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PACKERLAND REPORT

OPTIMAL METHODS FOR HOT PROCESSING BEEF CARCASSES

Progress Report

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OVERALL SUMMARY AND RECOMMENDATIONS

I. Ground Beef

A. Hot processed ground beef is equal to or superior to patties prepared from chilled beef in palatability, physical, and chemical properties.

B. Electrical stimulation of the mature beef carcass had no practical effect on ground beef palatability or cooking properties.

C. Increased time postmortem for boning resulted in increased cooking losses.

D. The bacteriological quality of stored ground beef from hot boned beef carcasses was equal to or superior to ground beef prepared from chilled beef.

Recommendations

1. To improve bacteriological quality, hot bone carcasses on the rail rather than on the table.

2. Hot bone carcasses within 4 hr postmortem to avoid water loss during cooking.

3. Avoid using chilled plates since they tend to increase the bacterial loads. If chilled plates are necessary, make certain they are fresh and in good condition.

II. Hot Boning Choice and Good Grade Beef

A. Hot boned primals have shapes, and fat and lean color similar to cold boned cuts.

B. Hot boned primals yield larger cuts than cold boned cuts.

C. Hot boned primals hold their vacuum better than cold boned cuts.

D. Hot boned primals have less purge in the bag than cold boned cuts.

E. Electrical stimulation increased tenderness in ribeyes of all carcasses.

F. If chilled for 20 days, electrical stimulation was not needed on hot or chilled cuts.

G. Differences in microbial growth between hot and cold boned cuts were small.

Recommendations

1. Electric shock Choice and Good grade carcasses scheduled for hot boning.

2. Remove hot primals within 2 to 4 hr postmortem. Avoid boning cuts less than 2½ hr for Choice carcasses and 4 hr for Good carcasses.

3. Do not freeze before 24 hr postmortem.

4. Bone on the rail to improve microbial quality of the meat.

III. Hot Boning Mature cows

A. Electrical stimulation does not appear to be necessary to produce adequate tenderness provided some type of mechanical or chemical treatment is used.

B. Immediate freezing increases the toughness of hot and cold boned primals. Mechanical and enzymatic tenderization offsets some of the toughening from rapid freezing.

C. Storing for 7 or 14 days prior to freezing produced the most tender product.

D. There appears to be no practical difference in the microbiological counts between hot and cold boned cuts.

Recommendations

1. Even though electrical stimulation had no consistent effect on tenderness you might want to consider using it as a safeguard.

2. Hot bone cows within 4 hr postmortem.

3. Hot bone carcasses on the rail to improve the microbial quality of the meat.

4. Chill cuts up to 14 days to improve tenderness.

5. Do not freeze cuts before 24 hr postmortem.

IV. Comparison of PVC film overwrap with electric shock on carcass traits and palatability.

A. Electrical stimulation had significant effects on decreasing heat-ring and improving lean color, texture and tenderness.

B. PVC film overwrap contributed little above the effects of electrical stimulation.

Recommendations

1. Do not use PVC film overwrap.

2. Use electrical stimulation on all carcasses to be graded.

V. Methods for Electrical stimulation

Much research is needed to determine the proper system for electrical stimulation. Questions yet to be answered include:

1. Amount of current.
2. Duration of shock-time.
3. DC or AC current.
4. Continuous or off-on shocks.
5. When to shock - sides or hide on.
6. Frequency of current.

New Zealand, England, Texas A & M, and the Meat Science Research Lab, USDA are working on these problems but final answers are not yet available. Some examples from different institutions are:

New Zealand
<30 cycles per sec. DC or AC continuous shock less than 2 minutes.

England
25 cycles per sec DC
700 volts
continuous shock
3000 pulses over 2 minutes

Texas A&M
60 cycles per sec AC
550 volts
intermittant shock
20-30 shocks over 60 sec period

USDA
60 cycles per sec AC
1.5 Amp (variable voltage)
intermittant over 2 or 3 min 1 sec on ½ sec off.

Introduction

Since January of this year the Meat Science Research Laboratory has been cooperating with Norval Dvorak and Packerland International to investigate optimal methods for hot processing beef. This report is a progress report relating our results and conclusions to date. Some of the data has not been statistically analyzed but trends can be established by evaluating means. The data from this research will ultimately be published in scientific journals. Papers that have been completed and submitted for publication can be found in the appendix.

GROUND BEEF PRODUCED FROM HOT AND COLD BONED BEEF.

Introduction

Two projects were conducted on ground beef at Packerland. The first project did not use electrical stimulation because it was felt that it might adversly affect the water holding properties of the ground beef. We also felt that perhaps the mechanical tenderization and enzyme dip would tenderize the steak and roast cuts sufficiently to preclude the need for electrical shock. The results of the steak and roast portion will be discussed later in this report but generally, preliminary results revealed that ribeye steaks were borderline in tenderness even though they had been tenderized. Therefore, another project was initiated to investigate the effect of electrical shock on cooking and sensory properties of ground beef and to evaluate the effects on the tenderness of steaks and roasts.

Palatability of Hot and Cold Processed Ground Beef

I. Unstimulated.

Table 1 presents the design of the first project on ground beef. Hot processed ground beef was prepared by three methods as outlined in table 1. Overall palatability and shear force values are presented in table 2. Hot processed ground beef was significantly more tender (panel and shear) and more juicy. The differences in juiciness are large and important. Table 3 compares the three systems of preparation with the control (chilled).

TABLE 1. Design-Unstimulated

	PREPARATION METHODS[a]							
	1 (Hot) Batch		2 (Hot) Batch		3 (Hot) Batch		Control (Chill[2]D) Batch	
	A	B	A	B	A	B	A	B
N= 4 sides per batch								

[a]Method 1: Kidney plate x 1/8 in final.

Method 2: Kidney plate x ½ in x 1/8 in final.

Method 3: No choice plates; Kidney plate x ½ in x 1/8 in final.

Control: ½ in x 1/8 in final.

TABLE 2. Mean palatability and shear force values for ground beef prepared from hot and chilled muscle. -Unstimulated

	TYPE OF PROCESSING	
TRAIT	HOT	CHILLED
Tenderness[a]	5.69[e]	5.22[f]
Connective tissue[b]	4.26[e]	4.38[e]
Juiciness[c]	5.47[e]	4.75[f]
Flavor intensity[d]	5.23[e]	5.27[e]
Max. Shear force, kg.	10.99[e]	11.96[e]

a. 8 = extremely tender and 1 = extremely tough.

b. 8 = none and 1 = abundant amount.

c. 8 = extremely juicy and 1 = extremely dry.

d. 8 = extremely intense and 1 = extremely bland.

n = 30 observations per mean.

e,f: means in the same row with different superscripts are significantly different ($P < .05$).

TABLE 3. Comparison of palatabilty traits of three systems of grinding hot, processed beef.-Unstimulated

TRAIT	HOT PROCESSED BEEF METHOD OF GRINDING[a] 1	2	3	control chilled
Tenderness[b]	5.48[f]	5.90[f]	5.68[f]	5.22
Connective tissue[c]	4.06[f]	4.48[f]	4.24[f]	4.38
Juiciness[d]	5.36[f]	5.61[f]	5.43[f]	4.75
Flavor intensity[e]	5.39[f]	5.37[f]	4.93[g]	5.27
Max. Shear force, kg.	11.19[f]	10.35[f]	11.38[f]	11.96

[a]1 = kidney plate x 0.32cm plate.
2 = kidney plate x 1.27cm plate + 0.32cm plate.
3 = kidney plate x 1.27cm plate + o.32cm plate (no Choice plates added as in 1 and 2).
[b]8 = extremely tender and 1 = extremely tough.
[c]8 = none and 1 = abundant amount.
[d]8 = extremely juicy and 1 = extremely dry.
[e]8 = extremely intense and 1 = extremely bland.
[fg]Means in the same row with different superscripts are significantly different (P <.05).

There were few important differences among the three methods for preparing hot ground beef. All three hot processed treatments were equal to or superior to the control.

II. Stimulated.

Palatability and cooking loss data from the second study involving electrical stimulation effects on ground beef are presented in table 4. Ground beef was prepared from lean that had either been shocked or not shocked and removed from the carcass at 1, 3 or 24 hours postmortem. Electric shock had no apparent effect on any palatability trait. Ground beef prepared from lean boned at 1 or 3 hours postmortem appeared to be slightly more tender then the 24 hour group. Cooking losses increased. These differences were large and important.

Table 4. Mean palatability of patties prepared from stimulated and unstimulated beef.

	Tenderness	Juiciness	CTA	Flavor Int.	% Cooking Loss
1 hr shock	5.0	4.6	3.6	4.7	34.54
1 hr no shock	5.4	4.9	3.8	4.8	33.37
3 hr shock	5.0	4.5	3.8	5.0	38.76
3 hr no shock	4.9	4.4	4.0	5.0	40.37
24 hr shock	4.6	4.4	3.7	5.0	43.30
24 hr no shock	4.5	4.1	3.8	4.9	45.59

Cooking properties of hot and cold processed ground beef.

I. Unstimulated.

Cooking property data from the first study (unstimulated) is presented in tables 5 & 6. Hot processed ground beef had significantly (important) less cooking loss than the chilled patties. Degree of doneness, percent height change (thickness) and thaw loss were not different but hot patties had significantly less percent diameter change. This is important for fast food chains that need constant patty diameter to fill bun area. Table 6 presents similar results for all grinding methods. Grinding method 1 (kidney plate x 1/8 in final) had the greatest percent diameter change among the hot processing methods. This was supported by the largest cooking loss. The triple grind with no added choice plates appeared to give the best results (method 3). Before we recommend a triple hot grind I would like to compare it to the ½ x 1/8 in grind. I doubt if there would be a significant difference.

II. Stimulated.

Data for cooking losses was presented in table 4. The remainder is still being computed.

Chemical composition of unstimulated hot and cold processed ground beef.

Table 7 presents data for pH, fat and moisture from hot and chilled beef patties. Since the thawed pH's were not different this indicates that the hot processed beef patties reached their ultimate pH before freezing. If they had not the muscle would have gone into thaw rigor which would likely have resulted in greater water loss during cooking and decreased tenderness. The fat and moisture content of all patties were not statistically different.

TABLE 5 Cooking properties of ground beef prepared from hot and chilled muscle. -Unstimulated.

TRAIT	TYPE OF PROCESSING	
	HOT	CHILLED
Total cooking loss, %	33.85[b]	41.06[c]
Degree of doneness[a]	2.32[b]	2.45[b]
Diameter change, %	14.93[b]	19.32[c]
Height change, %	16.06[b]	14.04[b]
Thaw loss, %	5.39[b]	6.21[b]

a 8 = rare and 1 = well done

bc means in the same row with different superscripts are significantly different ($P < .05$).

TABLE 6. Comparison of Cooking properties of three systems of grinding hot beef-Unstimulated.

TRAIT	HOT PROCESSED BEEF METHOD OF GRINDING[a] 1	2	3	control chilled
Total cooking loss, %	36.48[c]	35.04[c]	30.02[c]	41.06
Degree of doneness[b]	2.05[c]	2.60[c]	2.30[c]	2.45
Diameter change, %	16.53[c]	14.17[d]	14.08[d]	19.32
Height change, %	18.24[c]	20.76[c]	9.17[c]	14.04
Thaw loss, %	5.47[c]	6.23[c]	4.48[c]	6.21

b 8 = rare and 1 = well done.

cd means in the same row with different superscripts are significantly different (P< .05).

TABLE 7. Chemical properties of ground beef prepared from hot and chilled muscle.

TRAIT	TYPE OF PROCESSING	
	HOT	CHILLED
PH raw, frozen	5.52[a]	5.46[a]
PH raw, thawed	5.37[a]	5.32[a]
PH cooked	5.50[a]	5.46[a]
H_2O, raw, %	62.11[a]	62.29[a]
fat, raw, %	20.01[a]	19.55[a]
H_2O, cooked, %	52.10[a]	48.60[b]
Fat, cooked, %	21.10[a]	21.80[a]

ab means in the same row with different superscripts are significantly different ($P < .05$).

Table 8 presents a comparison of proximate composition values for patties prepared from hot or chilled beef. As expected, the percent fat, moisture, or protein did not differ statistically in the raw sample when comparing hot versus chilled patties.

Cooking losses were 33.85% and 41.06% for the hot and chilled patties, respectively. Therefore, a 100 gram raw patty from hot beef will be expected to yeild a 66.15 gram cooked patty. As can be seen from table 1, most of the weight loss during cooking was water, followed by fat. Patties from chilled beef lost 41.06% weight during cooking yielding, on the average, a 58.94 gram patty. The amount of water and fat lost from the chilled patty was significantly greater than in the hot patty. Protein was not different. It must also be assumed that loss of fat and water also results in the loss of some fat and water soluble nutrients.

In conclusion, it appears that there are no differences in raw proximate composition of patties prepared from hot or chilled beef. The chilled patty lost more fat and water during cooking. This can be attributed to the slower rate of pH decline in the hot beef muscle and thus less water loss during cooking. Also, since the hot patty was significantly more tender and juicy it can be assumed that less of the patty would be left on the plate.

Table 8. Proximate composition of raw and cooked patties prepared from hot and chilled beef.

Raw patty = 100 grams, cooked patty hot = 66.15 grams and chilled patty = 58.94 grams

Trait	Raw			Cooked[a]		
	Hot grams	Chilled grams		Hot grams	Chilled grams	
Fat	20.01	19.55	NS	14.02	12.84	*
H_2O	62.11	62.29	NS	34.46	28.64	**
Protein[b]	15.88	16.16	NS	16.33	16.27	NS
ASH[b]	1.5	1.5	NS	1.00	0.88	NS

[a]Cooking loss hot = 33.85%; chilled = 41.06%
[b]Ash and protein calculated by difference

Each value is the average of 50 observations.

*Statist. different at P<.05)
**Statist. different at P<.01
N.S. Not statistically different.

Bacteriological quality of ground beef prepared from hot and chilled beef carcasses (unstimulated).

The bacteriological quality of ground beef chub packs prepared from "hot" boned beef sides (2 h postmortem) and opposite conventionally chilled sides (24 h at 3 C) were compared at the time of preparation and at 3-day intervals up to 45 days of storage at 0 C. Aerobic plate counts (APC's) in ground beef from "hot" boned beef were either significantly lower or not significantly different from APC's in ground beef from chilled carcasses (table 9). There were no significant differences of any practical importance in Most Probable Numbers (MPN's) of coliforms and *Escherichia coli* between "hot" and cold boned ground beef (table 10). Ground beef prepared from "hot" boned beef offers tremendous possibilities in energy conservation to the meat industry. The bacteriological quality of ground beef from "hot" boned carcasses does not limit, but rather enhances the feasibility of boning carcasses before chilling.

Table 9. Effect of storage at 0 C on APC's in ground beef prepared from "hot" and chilled beef carcasses[a]

Days of storage	APC(5 C)		APC (20 C)		APC (35 C)	
	Hot	Chilled	Hot	Chilled	Hot	Chilled
0	4.30kl[b]	3.94lm	5.05g-j	4.96hij	5.13g	5.13g
3	4.17l	3.44m	5.06g-j	4.89ij	5.06g	4.99g
6	4.01lm	3.98lm	5.15g-j	5.06g-j	5.11g	5.18g
9	3.95lm	4.35kl	4.90ij	4.96hij	5.01g	5.22fg
12	4.06l	4.50jkl	5.09g-j	4.92ij	5.27fg	4.99g
15	4.14l	4.47jkl	5.04g-j	4.79j	5.04g	4.92g
18	4.04lm	4.81jk	5.14g-j	5.17ghi	5.19g	5.07g
21	4.27kl	5.06hij	4.78j	5.36fg	4.93g	5.34fg
24	4.06l	5.94d-g	5.01g-j	6.17e	4.99g	5.97de
27	4.26kl	6.14c-f	5.10g-j	6.22e	5.27fg	6.06d
30	4.95ij	5.73efg	5.58f	5.31fgh	5.31fg	5.91de
33	5.60fgh	6.46a-d	5.56f	6.60cd	5.62ef	6.49bc
36	6.52a-d	6.24b-e	6.38de	6.62cd	6.28cd	6.48bc
39	6.75ab	6.70abc	6.83abc	6.75bc	6.74ab	6.68ab
42	5.40ghi	5.66efg	6.70bcd	7.13a	6.71ab	7.03a
45	6.85a	7.02a	6.83abc	7.00ab	6.78ab	6.83ab

[a]Each value is the mean $\log_{10}$ count/g of 3 chub packs.
[b]Values for a given APC incubation temperature followed by different letters are significantly ($P \leq 0.05$) different according to Duncan's multiple range test (2).

Table 10. Effect of storage at 0 C on MPN's of coliforms and *Escherichia coli* in ground beef prepared from "hot" and chilled beef carcasses[a]

Days of storage	Coliforms		*E. coli*	
	Hot	Chilled	Hot	Chilled
0	12b[b]	14b	0c	7abc
3	7b	6b	0c	6abc
6	5b	17b	0c	3abc
9	2b	1b	0c	1c
12	9b	1b	9ab	1c
15	6b	0b	0c	0c
18	0b	12b	0c	2bc
21	3b	14b	0c	0c
24	4b	3b	0c	0c
27	22b	4b	0c	4abc
30	8b	10b	0c	10a
33	13b	151a	0c	0c
36	1b	19b	0c	1c
39	0b	5b	0c	5abc
42	0b	5b	0c	4abc
45	3b	4b	0c	1c

[a]Each value is the mean MPN/g of 3 chub packs.
[b]Values for a given bacterial classification followed by different letters are significantly ($P \leq 0.05$) different according to Duncan's multiple range test (2).

Ground Beef Conclusions

1. Hot processed ground beef is equal to or superior to patties prepared from chilled beef in palatability, physical, and chemical properties. Patties prepared from hot processed beef were significantly more tender and juicy and lost much less water during cooking.
2. Hot processed beef patties had significantly less percent diameter change than chilled patties.
3. Electrical stimulation of the beef carcass had no practical effect on ground beef palatability or cooking properties.
4. Increased time postmortem for boning resulted in increased cooking losses.
5. The bacteriological quality of ground beef from "hot" boned beef carcasses was equal to or superior to ground beef prepared from chilled beef.

SYSTEMS FOR HOT BONING CHOICE AND GOOD GRADE BEEF

Introduction

Hot processing will likely be accepted by industry first in the production of ground or sausage beef; second in the use of primals from mature beef cows and last from young fed beef. The objection most often discussed to hot boning of young beef primals is that it will change the shape and thus require changes in marketing practices. The second problem most often cited is the lack of a USDA grading system for hot boned cuts. Our second visit to Packerland involved a project divided into two phases. Phase one was designed to investigate the effects of hot boning on storage properties of primal cuts. Phase II investigated the effects of storage treatment, electrical stimulation, boning time postmortem, and type of carcass on palatability, cooking, and microbiological properties of all beef primals.

Phase I - Storage properties of hot and cold boned beef cuts.

Each primal cut was scored for shape as compared to normal before it went into the bag and when it was removed following 20 days storage at 3 C. Ratings in the 6 to 8 category were close enough to normal to be considered acceptable in the marketplace. Data for "shape" are presented in table 11. As expected, all cold boned cuts were in the 6 to 8 range. All hot boned cuts were in the same range with the exception of the chuck roll and knuckle. The shape of the chuck roll was improved considerably when it was placed in a liver box and chilled overnight. The chuck roll retained its shape through the storage period. Its likely that the shape of all cuts could be improved if bags were used that were closer to the actual size of the cut. In this comparison, all bags were of the same size. Some were much too large.

Each cut was rated for fat color immediately after boning and after 20 days vacuum storage. A rating of 3 to 5 was considered "acceptable". Mean values for each cut are presented in table 12. Generally, fat from hot boned cuts were whiter initially and after 20 days when compared to cold boned cuts. These differences are not large enough to be of practical importance.

Each cut was rated for lean color immediately after boning and after 20 days vacuum storage. A rating of 5 to 7 was considered acceptable. As expected, the initial color of hot boned cuts was much darker than cold boned cuts. The differences between hot and cold cuts were small after vacuum storage. The values at 20 days are somewhat misleading since the color was evaluated immediately after removing from the vacuum bag --- before they had time to bloom. Subsequent research from our laboratory

Table 11. A comparison of shape of hot and cold boned beef cuts after 0 and 20 days of storage.

Cut	Hot Boned[a]		Cold Boned[b]	
	Initial	20 days	Initial	20 days
Brisket	7.4	6.4	7.8	7.1
Clod	7.0	7.3	7.8	6.9
Chuck roll	2.5	5.4	7.3	6.3
Ribeye	7.0	6.8	8.0	7.4
Strip	6.3	5.7	7.8	7.8
Tenderloin	6.5	6.2	8.0	6.9
Top sirloin	7.3	6.9	8.0	7.3
Knuckle	6.7	4.6	7.3	6.4
Inside round	7.7	6.9	7.5	6.9
Gooseneck	7.5	7.3	7.7	7.0
average	6.6	6.4	7.7	7.0

a. boned 1 hr postmortem.
b. boned 48 hr postmortem.
8 = normal shape and 1 = abnormal shape

Table 12. A comparison of fat color ratings of hot and cold boned beef cuts after 0 and 20 days of storage.

	Fat Color Ratings[a]			
	Hot Boned[b]		Cold Boned[c]	
Cut	Initial	20 days	Initial	20 days
Brisket	4.1	4.1	2.9	3.5
Clod	3.5	3.9	2.9	3.5
Chuck roll	2.6	2.7	2.9	2.2
Ribeye	3.0	3.7	2.9	2.2
Strip	4.0	4.3	2.9	4.0
Tenderloin	2.8	3.6	2.9	3.3
Top sirloin	3.5	5.0	2.9	4.0
Knuckle	2.6	2.9	2.9	2.3
Inside round	3.5	3.8	2.9	3.4
Gooseneck	3.8	4.1	2.9	2.7
average	3.3	3.8	2.9	3.1

a. Fat color: 5 = white, 1 = yellow
b. boned 1 hr postmortem
c. boned 48 hr postmortem

indicates that color uniformity is superior in hot boned cuts due to the uniform pH decline. PH decline, is not uniform in cold boned cuts because of the differing rates of chill from the outside to the inside of large muscles. This is also what causes "heat-ring". Heat-ring will be discussed in more detail later in the report.

Individual cut weights are presented in table 14. Hot boned cuts were generally heavier than cold boned cuts. This is not unexpected since hot muscle is easier to remove from the bone than cold meat. Packerland boners required 35 to 40% less time to hot bone sides (on the rail) as compared to Packerland's average boning time on the table. Hot boned cuts lost slightly less weight during storage as compared to cold boned cuts. I would estimate that with more practice in hot boning, the difference in yield would be greater.

After 20 days of storage in the vacuum bag at 3 C each cut was rated for the degree of vacuum or leakage. Ratings of 1-3 were typical of bags with almost no visable purge and a very tight adherence to the surface of the meat. Ratings of 7-9 were borderline and 10-15 were extreme leakers. Means are presented in table 15. On the average, hot boned cuts retained their vacuum better than cold boned cuts. Generally, cold boned cuts had much more visable purge as compared to the hot boned cuts. One could almost identify cold boned cuts by the amount of purge in the bag. The differences were more pronounced in leaner cuts such as the clod, knuckle, inside round and gooseneck.

Work from our laboratory, New Zealand and England indicates that cattle can be hot boned without danger of cold shortening when the pH approaches 6.0.

Table 14. A comparison of individual weights of hot and cold boned beef cuts after 0 and 20 days of storage.

	Weights, kg			
	Hot Boned[a]		Cold Boned[b]	
Cut	Initial	20 days	Initial	20 days
Brisket	8.87	8.73	8.43	8.31
Clod	16.91	16.84	16.04	15.92
Chuck roll	21.41	21.34	18.76	18.67
Ribeye	7.73	7.29	7.36	7.52
Strip	10.44	10.37	9.41	9.07
Tenderloin	6.55	6.44	5.19	5.05
Top sirloin	9.79	9.77	9.83	9.72
Knuckle	8.91	8.90	9.55	9.50
Inside round	17.69	17.63	17.52	17.35
Gooseneck	20.36	20.29	18.64	18.54
average	12.86	12.76	12.07	11.96

a. boned 1 hr postmortem.
b. boned 48 hr postmortem.

Table 15. A comparison of vacuum-leakage of hot and cold boned beef cuts after 20 days of storage.

	Leakage Ratings[a]	
Cut	Hot	Cold
Brisket	2.5	5.5
Clod	4.6	7.5
Chuck roll	5.6	6.0
Ribeye	3.1	6.7
Strip	7.3	7.9
Tenderloin	5.8	8.7
Top sirloin	6.5	7.1
Knuckle	3.5	9.9
Inside round	5.2	10.0
Gooseneck	5.8	7.8
average	5.0	7.7

a. 15 = extreme leakage and 1 = no visable leakage.

Table 16. A comparison of pH of hot and cold boned beef cuts after removal from the carcass.

Cut	pH Hot	pH Cold
Brisket	6.05	5.75
Clod	6.16	5.90
Chuck roll	6.20	5.73
Ribeye	6.12	5.68
Strip	6.04	5.73
Tenderloin	6.12	5.92
Top sirloin	6.02	5.66
Knuckle	6.02	5.76
Inside round	6.07	5.65
Gooseneck	6.04	5.68

a. boned 1 hr postmortem.
b. boned 48 hr postmortem.

Data from table 16 indicates that the pH of all hot boned cuts were either at or near pH 6.0 at the time of boning.

Phase II Effect of storage treatment, type of carcass, shock treatment and bone time on palatability of ribeye steaks.

The design for this phase is outlined in table 17. Choice and Good grade carcasses were selected and randomly alloted to various treatments. The ribeye was removed from shocked or non-shocked sides at 1, 4 or 48 hr postmortem. After removing from the carcass, the vacuum packaged cut was either frozen immediately (treatment #1); chilled 24 hr at 3 C on racks then frozen in boxes (treatment #2); or chilled 24 hr on rack then moved to boxes for 19 days at 3 C.

Results for tenderness are presented in table 18. Generally, electrical shock increased ribeye tenderness in both Choice and Good grade carcasses. Except for the 1 hr boning time, ribeyes of acceptable tenderness (greater than 5.0) were produced from electrically stimulated carcasses that were frozen immediately. Generally, acceptable tenderness can be produced under the following conditions:

1. Shock and 4 to 48 hr bone and immediate freeze for Choice.
2. Shock and 1 to 48 hr bone and 24 hr chill before freezing in Choice carcasses. Should not bone before 4 hr in Good carcasses.
3. 20 day chill produced acceptable product with any treatment.

In actual boning situations, it is unlikely that carcasses will be boned consistently at 1 hr postmortem. In regard to tenderness, I would recommend that carcasses be shocked; boned from 2 to 4 hr postmortem and not frozen prior to 24 hr. This procedure allows a considerable safety margin.

Table 17. Design Phase II.

Storage Treatment[a]	Type of Carcass	Electric Treatment	Boning Time (hr) 1	4	48
	Choice	Shock	2 sides	2	2
1[b]		No Shock	2	2	2
	Good	Shock	2	2	2
		No Shock	2	2	2
	Choice	Shock	2	2	2
2[c]		No Shock	2	2	2
	Good	Shock	2	2	2
		No Shock	2	2	2
	Choice	Shock	2	2	2
3[d]		No Shock	2	2	2
	Good	Shock	2	2	2
		No Shock	2	2	2

a. all cuts were vacuumized.
b. 1 = frozen at -40 C on rack 24 hr then moved to box and stored at -4 C.
c. 2 = chilled 24 hr at 2 to 3 C on rack then moved to box and frozen and stored at -40 C.
d. 3 = chilled 24 hr at 2 to 3 C on rack then moved to box for 19 days storage at 2 to 3 C.

Table 18. Phase II Palatability of ribeye steaks.

System	Grade of Carcass	Panel Tenderness: Shock[b] or No Shock	Hot Bone Time[a]: 1 hr	4 hr	48 hr
Immediate Freeze	Choice	S	4.6	5.4	6.4
		NS	5.7	4.7	5.7
	Good	S	4.7	4.5	5.9
		NS	4.6	4.2	5.4
24 hr chill then freeze	Choice	S	5.4	5.5	6.7
		NS	3.6	3.5	4.8
	Good	S	4.3	5.8	6.1
		NS	3.5	3.9	5.5
20 day chill then freeze	Choice	S	6.6	6.4	6.3
		NS	6.5	6.2	6.6
	Good	S	7.4	7.0	7.0
		NS	5.5	7.0	6.6

a. 8 = extremely tender and 1 = extremely tough.
b. S = shock NS = no shock.

Ratings for connective tissue are presented in table 19. Carcasses that were electrically stimulated tended to have less panel detectable connective tissue. Boning times had only slight effects as did storage treatments.

Ratings for juiciness are presented in table 20. The differences in juiciness were slightly in favor of stimulated carcasses. Future statistical analysis will likely prove these differences to be not significantly different. Neither boning time nor storage treatment appeared to affect juiciness.

Flavor intensity ratings (table 21) were not affected by electrical or storage treatments but those ribeyes removed at 1 hr postmortem had a slightly lower flavor ratings than those boned at 4 or 48 hr. Those differences were very small and may be of no importance.

Cooking Properties

Means for total cooking loss are outlined in table 22. Cooking loss appeared to be slightly greater in Choice carcasses that were electrically stimulated. The reverse was true for Good carcasses. It is doubtful that a meaningful trend can be established from this data. All values are in the range normally expected for ribeye steaks.

Table 19. Phase II. Palatability of ribeye steaks.

System	Grade of Carcass	Shock[b] or No Shock	Panel Rating for Connective Tissue: Hot Bone Time[a] 1 hr	4 hr	48 hr
Immediate freeze	Choice	S	6.1	7.2	7.4
		NS	6.9	5.9	6.8
	Good	S	5.8	5.8	6.9
		NS	6.4	5.8	6.6
24 hr chill then freeze	Choice	S	6.0	7.1	7.3
		NS	5.2	4.8	6.3
	Good	S	5.8	6.9	7.0
		NS	6.7	5.6	7.0
20 day chill then freeze	Choice	S	7.4	6.8	7.1
		NS	6.6	6.7	7.4
	Good	S	7.3	7.2	7.3
		NS	6.6	7.5	7.5

a. 8 = none and 1 = abundant amount.
b. S = shock NS = no shock

Table 20. Phase II Palatability of ribeye steaks.

Panel Juiciness

System	Grade of Carcass	Shock[b] or No Shock	Hot Bone Time[a] 1 hr	4 hr	48 hr
Immediate freeze	Choice	S	5.4	5.4	5.5
		NS	5.5	5.3	5.5
	Good	S	5.2	5.1	5.0
		NS	5.2	5.4	5.4
24 hr chill then freeze	Choice	S	5.7	4.7	5.3
		NS	5.2	5.0	5.4
	Good	S	4.7	5.8	5.4
		NS	5.0	4.4	4.8
20 day chill then freeze	Choice	S	5.5	5.2	4.8
		NS	5.8	5.9	5.1
	Good	S	5.8	5.9	5.4
		NS	4.6	5.3	5.4

a. 8 = extremely juicy.
b. S = shock NS = no shock

Table 21. Phase II. Palatability of ribeye steaks.

Panel Flavor Intensity

System	Grade of Carcass	Shock[b] or No Shock	Hot Bone Time[a] 1 hr	4 hr	48 hr
Immediate freeze	Choice	S	4.6	5.4	5.2
		NS	4.4	4.8	5.0
	Good	S	4.8	4.5	5.0
		NS	4.8	4.8	5.2
24 hr chill then freeze	Choice	S	4.6	5.0	5.5
		NS	4.5	4.3	4.7
	Good	S	4.4	4.9	5.2
		NS	5.2	4.1	4.9
20 day chill then freeze	Choice	S	5.3	5.7	5.5
		NS	5.5	5.7	5.7
	Good	S	5.5	5.7	5.6
		NS	4.9	5.7	5.1

a. 8 = extremely intense 1 = extremely bland.
b. S = shock NS = no shock

Table 22. Phase II. Total cooking loss of ribeye steaks.

System	Grade of Carcass	Shock[a] or No Shock	% Cooking Loss Hot Bone Time 1 hr	4 hr	48 hr
Immediate freeze	Choice	S	33.1	37.0	38.2
		NS	27.2	37.3	33.9
	Good	S	34.4	35.3	36.0
		NS	27.9	33.4	35.8
24 hr chill then freeze	Choice	S	31.6	38.8	37.0
		NS	33.7	37.3	36.8
	Good	S	29.6	32.4	33.0
		NS	39.4	36.4	32.1
20 day chill then freeze	Choice	S	32.0	31.6	41.1
		NS	30.8	30.3	34.4
	Good	S	29.1	29.7	31.0
		NS	37.2	37.0	32.9

a. S = Shock NS = No Shock

Conclusions

1. Hot boned primals have shapes, and fat and lean color similar to cold boned cuts.

2. Hot boned primals yield larger cuts than cold boned cuts.

3. Hot boned primals hold their vacuum better than cold boned cuts.

4. Hot boned cuts have less purge in the bag.

5. Electrical stimulation increased tenderness in ribeyes of Choice and Good carcasses.

6. If chilled for 20 days, electrical stimulation was not needed on hot or chilled cuts.

7. Although data is not presented, differences in microbial growth between hot and cold boned cuts were small.

SYSTEMS FOR HOT BONING MATURE COWS

Two projects were conducted on mature cow beef. The first study involved the hot and cold boning of the top rounds, strips and storing by one of 4 methods. Electrical stimulation was not used.

1. film wrap and freeze
2. film wrap and chill for 7 days
3. vacuum package and chill for 14 days
4. film wrap and freeze.

Roasts from methods 1-3 were mechanically tenderized and enzyme dipped while those in group 4 were not.

Palatability results are presented in tables 23 and 24. Mean palatability ratings for strip steaks are outlined in table 23. Cold boned cuts were slightly more tender than hot boned cuts. A tenderness rating of 5.0 is usually considered acceptable. Cuts (hot or cold boned) stored at 3 C for 7 or 14 days were more tender than cuts frozen immediately. Cuts (hot or cold boned) receiving no mechanical or enzymatic tenderizing treatment (treatment 4) were much tougher than those in treatments 1-3.

Results for top round roasts are presented in table 24. Hot boned roasts were as tender as cold boned ones. Again, storage at 7 or 14 days improved the tenderness. Freezing produced slightly tougher and dryer samples as compared to chilled cuts.

Since the tenderness of unshocked cow primals was borderline in the first study, another project was initiated to evaluate the effects of electrical stimulation and boning time on palatability. Results for the top round are presented in tables 25 thru 28. Values for tenderness are

Table 23. Mean palatability ratings for strip steaks from mature cows.

Hot Boned

Treatment	Tenderness	Juiciness	CTA	Flavor Intensity
1	4.41	5.51	5.30	5.06
2	5.39	5.08	6.21	5.05
3	5.65	5.13	6.09	5.58
4	2.81	4.85	4.02	5.19

Cold Boned

Treatment	Tenderness	Juiciness	CTA	Flavor Intensity
1	5.05	5.44	5.71	4.75
2	6.04	5.04	6.69	5.25
3	6.28	4.74	6.61	5.17
4	4.32	5.11	5.46	5.39

1 = film wrap and freeze
2 = film wrap, stored 7 days
3 = vacuum packaged, stored 14 days
4 = film wrap and freeze - no blade or enzyme
all steaks were broiled to 70 C internal temperature

Table 24. Mean palatability ratings of top round roast (cooking method = roasting).

Hot Boned

Treatment	Tenderness	Juiciness	CTA	Flavor Intensity
1	3.66	4.40	3.92	4.66
2	4.05	3.58	4.29	4.64
3	4.44	4.26	4.28	5.33
4	3.53	3.51	4.09	4.52

Cold Boned

Treatment	Tenderness	Juiciness	CTA	Flavor Intensity
1	3.86	3.99	3.84	4.61
2	4.02	3.61	4.40	5.07
3	4.48	4.19	4.18	4.91
4	3.47	3.79	4.41	5.13

1 = film wrap and freeze
2 = film wrap, chill 7 days
3 = vacuum packaged, chilled 14 days
4 = film wrap and freeze - no blade or enzyme

outlined in table 25. Generally, shocking did not appear to enhance the tenderness of hot boned top rounds where as some improvement was noted in the cold boned carcasses. In some cases mechanical tenderization improved tenderness, while in others it did not.. This group of carcasses were tougher than the group in the first study. Generally, shocked carcasses were less juicy than control (table 26). Connective tissue ratings did not appear to be affected by shock treatment (table 27). The same trend was evident for ratings in flavor intensity (table 28).

Conclusions

1. Hot boning systems for mature cow primals is feasible.
2. Immediate freezing increases the toughness whether hot or cold boned. Mechanical and enzymatic tenderization offsets some of the disadvantages of immediate freezing.
3. Electrical stimulation does not appear to be necessary to produce adequate tenderness provided some type of mechanical or chemical treatment is used.
4. Although the data is not presented, there appears to be no practical difference in the microbiological counts between hot and cold boned cuts.

COMPARISON OF PVC FILM OVERWRAP WITH ELECTRIC SHOCK ON CARCASS TRAITS AND PALATABILITY

In order to evaluate the effect of film overwrap and electrical shock postmortem on carcass quality traits and palatability, 24 sides of beef were assigned to one of 4 treatments (table 29): (1) control - no electrical shock and cloth shroud only; (2) electrical shock and cloth shroud only; (3) no electrical shock and cloth shroud plus PVC film overwrap; and (4) electrical shock and cloth shroud plus PVC film overwrap. Carcasses were shocked within 1 hr postmortem and before chilling. Metal pins were placed in the muscles of the round near the achilles tendon and

in the muscles between the scapula and the thoracic vertebrae. Sides were chilled 18 hr at 2 to 3 C prior to ribbing. Following ribbing and a 15 min. "bloom" time, each side was evaluated for quality grade and yield grade characteristics and scored for "heat-ring", color, texture and firmness. Data for carcass traits, cooking properties and palatability are presented in tables 29-32. Electrical stimulation had significant effects on decreasing "heat-ring" and improving lean color, texture and tenderness. PVC film overwrap contributed little above the effects of electrical stimulation. These data suggest that electrical stimulation significantly decreased the incidence of "heat-ring" which could allow carcasses to be graded sooner than is current practice.

Table 25. Mean tenderness ratings for top round roast receiving postmortem electrical shock.

Treatment	Boning Time	Tenderi-zation[a]	Electrical Shock	No Electrical Shock
Film W	1 Hot	C	3.9	3.5
		T	3.6	3.3
Film Wrap and Freeze	3 Hot	C	2.9	2.6
		T	3.0	3.2
	24 Cold	C	3.9	4.1
		T	4.5	3.7
	1 Hot	C	3.4	3.2
		T	5.7	4.1
Film Wrap, Chill 24 hr and Freeze	3 Hot	C	3.6	3.8
		T	3.5	3.0
	24 Cold	C	4.4	3.9
		T	4.5	3.7

[a] c = control, no mechanical tenderization
t = mechanical tenderization only

Table 26. Mean juiciness ratings for top round roast receiving postmortem electrical shock.

Treatment	Boning Time	Tenderi-zation[a]	Electrical Shock	No Electrical Shock
Film Wrap and Freeze	1 Hot	C	3.9	4.5
		T	3.9	4.3
	3 Hot	C	3.6	3.6
		T	3.6	4.0
	24 Cold	C	3.8	3.5
		T	3.4	3.7
Film Wrap, Chill, and Freeze	1 Hot	C	5.3	3.6
		T	4.0	4.5
	3 Hot	C	4.1	4.4
		T	2.1	5.3
	24 Cold	C	3.4	4.2
		T	4.1	3.2

[a]c = control, no mechanical tenderization
t = mechanical tenderization only

Table 27. Mean connective tissue ratings for top round roast receiving postmortem electrical shock.

Treatment	Boning Time	Tenderi-zation[a]	Electrical Shock	No Electrical Shock
Film Wrap and Freeze	1 Hot	C	5.9	5.6
		T	5.4	5.1
	3 Hot	C	5.7	4.8
		T	5.3	5.2
	24 Cold	C	5.7	6.1
		T	6.1	5.4
Film Wrap, Chill, and Freeze	1 Hot	C	5.6	5.7
		T	5.9	6.0
	3 Hot	C	5.6	5.6
		T	4.6	5.1
	24 Cold	C	6.4	5.8
		T	5.9	5.9

[a]c = control, no mechanical tenderization
t = mechanical tenderization only

Table 28. Mean flavor intensity ratings for top round roast receiving postmortem electrical shock.

Treatment	Boning Time	Tenderi-zation[a]	Electrical Shock	No Electrical Shock
Film Wrap and Freeze	1 Hot	C	4.1	3.9
		T	4.0	4.2
	3 Hot	C	4.2	4.2
		T	4.0	4.2
	24 Cold	C	4.6	4.4
		T	5.0	4.7
Film Wrap Chill and Freeze	1 Hot	C	4.7	4.6
		T	4.6	4.2
	3 Hot	C	4.3	4.7
		T	4.6	4.1
	24 Cold	C	4.5	4.5
		T	4.6	4.7

[a]c = control, no mechanical tenderization
t = mechanical tenderization only

TABLE 29 EXPERIMENTAL DESIGN. [a]

Treatments	Treatments			
	Shroud (control)		Shroud and Film overwrap	
Electrical Shock	1 left 2 " 3 "	7 left 8 " 9 "	1 right 2 " 3 "	7 right 8 " 9 "
No Electrical Shock	4 left 5 " 6 "	10 left 11 " 12 "	4 right 5 " 6 "	10 right 11 " 12 "

a. 1-12 represents carcass numbers

TABLE 30 Average carcass traits for shroud, film and shock treatments.

Trait	Shroud (control)		Shroud and Film overwrap	
	N S[a]	E S[b]	N S[a]	E S[b]
Fat thickness over ribeye, cm	.18*	.37	.16	.38
Ribeye area, cm^2	78.58	77.74	77.23	77.29
Marketing	SM^-	SM	SL^+	SM
Lean maturity	A^-	A	A	A
USDA yield grade	2.0	2.6	2.0	2.6
USDA quality grade	C^-	C^-	G^+	C^-

a NS = not stimulated
b ES = electrically stimulated
* All means were not significantly different ($P<.05$)

TABLE 31 Average quality traits for shroud, film and shock treatments.

Trait	Shroud (control)		Shroud and Film overwrap	
	N S[a]	E S[b]	N S[a]	E S[b]
pH (raw)	5.88[i]	5.75[i]	5.70[i]	5.77[i]
Temperature, °C	1.83[i]	3.50[i]	3.78[i]	5.23[i]
Cooking losses, %	29.37[i]	31.74[i]	28.72[i]	30.23[i]
Heat ring [c]	12.33[i]	6.50[j]	10.33[i]	6.33[j]
Lean firm [d]	6.17[i]	5.83[i]	6.17[i]	5.83[i]
Lean color [e]	2.83[j]	4.17[i]	4.33[i]	5.17[i]
Lean texture [f]	4.50[j]	6.67[i]	4.67[j]	6.67[i]
Fat shrink [g]	3.50[j]	3.50[j]	6.33[i]	4.83[ij]
Lean shrink [h]	5.67[i]	2.17[j]	3.33[ij]	2.18[j]

a NS = non-stimulated
b ES = electrically stimulated
c heat ring 15 = extreme and 1 = none
d lean firm 8 = very firm and 1 = very soft
e lean color 8 = light grayish-red and 1 = very dark red
f lean texture 8 = fine and 1 = very coarse
g fat shrink 15 = none and 1 = extreme
h lean shrink 15 = none and 1 = extreme
ij means in the same row with different superscripts are significantly different ($P<.05$)

TABLE 32 Average sensory panel and shear valves for shroud, film and shock treatments.

Trait	Shroud (control)		Shroud and Film overwrap	
	N S[d]	E S[e]	N S[d]	E S[e]
M.F. Tenderness[a]	3.78[h]	4.89[fg]	4.04[gh]	4.98[f]
O.A. Tenderness[a]	3.79[h]	4.90[fg]	4.09[gh]	4.99[f]
Connective tissue AMT.[b]	5.82[f]	6.26[f]	5.82[f]	6.38[f]
Juiciness[c]	4.70[fg]	5.02[f]	4.42[g]	4.76[f]
Shear force, kg.	7.03[f]	5.37[g]	7.04[f]	5.77[g]

a. Muscle fiber tenderness and overall tenderness 1 = extremely tough and 8 = extremely tender.

b. Connective tissue amount 1 = abundant and 8 = none

c. Juiciness = 1 = extremely dry and 8 = extremely juicy

d NS = not stimulated

e ES = electrically stimulated

f-h = Means in the same row with different superscripts are significantly different ($P < .05$).

APPPENDIX

THE EFFECT OF ELECTRICAL STIMULATION ON LYSOSOMAL ENZYME ACTIVITY, pH DECLINE, AND BEEF TENDERNESS

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Introduction

Several studies have been reported on the effect of electrical stimulation on beef (Harsham and Deatherage, 1951; Chrystall and Hagyard, 1976; Smith *et al.*, 1977; and Savell *et al.*, 1977). Results of these experiments suggest that electrical stimulation will accelerate postmortem pH decline, hasten rigor development, and improve tenderness. Several investigators (Chrystall and Hagyard, 1976; and Davey *et al.*, 1976) have attributed the improved tenderness effects of electrical stimulation to prevention of "cold shortening." However, recent studies have failed to show consistent differences in sarcomere length of stimulated and unstimulated carcasses (Savell *et al.*, 1977 and Grusby *et al.*, 1976). Several workers (Dutson *et al.*, 1978; Smith *et al*; 1977) have suggested that some portion of the tenderization improvement derived from electrical stimulation may result from increased activity of the lysosomal enzymes in treated carcasses. Lysosomal enzymes are activated by low muscle pH (Tappel, 1966) and may partially contribute to meat tenderness by hydrolysing connective tissue (β-glucuronidase) and/or proteins (cathepsins).

To obtain an insight into the tenderization process, the present study was designed to evaluate the effect of electrical stimulation on lysosomal enzyme activity in carcasses resulting from stressed and unstressed steers.

Materials and Methods

In a 2x2 factorial, twelve steers of similar breeding and management history (USDA quality grade of low to average Good; USDA yield grade of 2.5 to 3.0 and 375-425 kg in weight) were randomly assigned to two antemortem treatment groups. One group of steers were not stressed (control) but allowed free access to feed and water prior to slaughter while another group were taken off feed and water for 48 hr prior to slaughter and stressed by exercising for 10 minutes every 3 hr for a total of 15 hr and then continuously for 30 min just prior to slaughter. The stress treatment was designed to deplete muscle glycogen in order to obtain a high pH by preventing the formation of lactic acid (Ashmore *et al.*, 1971). This treatment was performed to provide two different rates of pH decline.

At 1 hr postmortem, sides from unstressed and stressed carcasses were randomly exposed to two treatments (no electrical shock and electrical shock). Metal pins serving as electrodes were placed in the round muscle near the Achilles' tendon and in the muscles between the scapula and the thoracic vertebrae. Electrical stimulation was administered in impulses of 15 sec duration with intervals between impulses of approximately 1 sec. The treated sides were stimulated for a total of 3 min with 1 amp current passing through the carcass (145-268 volts; AC, 60HZ).

Longissimus muscle samples were excised at 0, 3, 6, 12, 24, and 48 hr poststimulation and analyzed immediately for pH and lysosomal enzyme activity using β-glucuronidase as a marker enzyme. After 48 hr chill at 2-3°C, two 2.5 cm thick steaks were removed, wrapped in freezer paper, and stored at -28°C for subsequent palatability evaluation using a 10-member descriptive attribute panel as described by Cross *et al*. (1978).

For pH determination, 10g of sample were homogenized with 50ml of cold 0.25M sucrose containing 0.02M KCl in a Sorvall Omni mixer for 20 sec at speed 6. The homogenate was filtered through two layers of cheese cloth and pH of the filtrate was determined before adjusting to 7.3. Subsequently, the filtrate was processed to obtain the soluble fraction for free activity of β-glucuronidase which was assayed according to Gianetto and deDuve (1955). The amount of soluble protein was determined by the modified biuret procedure (Gornall *et al*., 1949), using bovine albumin as standard.

Results and Discussion

Rate of pH decline is presented in figure 1. Electrically stimulated beef sides that were not stressed had the most rapid rate of decline ($P<.0001$) while the stressed sides (stimulated or unstimulated) had the slowest rate of pH decline. The nonstressed and unstimulated group (control) had a pH value of 6.50 at 1 hr postmortem (i.e. 0 hr poststimulation). This value falls in the range 6.48-7.04 reported in the literature (Moeller *et al*., 1976; McCollum and Henrickson, 1977; Shaw and Walker, 1977; and Tarrant and Mothersill, 1977).

The pH value dropped to 5.45 within 6 hr poststimulation (7 hr postmortem) in the nonstressed,stimulated group. Gilbert and Davey (1976) were able to obtain a pH of 5.49 in 5 hr using a higher

voltage (3600 V). In this study, 1 amp current delivering only between 145-268 volts was applied through the carcass. Stressed carcasses had higher ($P<.05$) ultimate pH (5.80 and 5.76 respectively for unstimulated and stimulated carcasses) when compared with the unstressed beef sides.

Davey et al. (1976) observed that tenderness is the palatability attribute most affected by electrical stimulation. Mean values for palatability and Instron shear force are presented in table 1. Carcasses from unstressed stimulated animals were rated significantly more tender than unstressed, unstimulated carcasses. This difference was supported by significantly different Instron shear force values between the same groups. The unstressed, stimulated carcasses had the least variability about the means for tenderness and Instron shear force. The differences in tenderness were large enough to be of practical importance. Carcasses from stressed animals were borderline in tenderness and were not significantly affected by electrical stimulation. Unstressed and stimulated carcasses were rated significantly lower in detectable connective tissue when compared to unstressed, unstimulated carcasses. It would appear from this data that electrical stimulation of stressed animals does little to enhance tenderness.

Analysis of variance revealed that there was no difference between treatments in the specific activity of lysosomal enzymes using β-glucuronidase as a marker enzyme.

Perhaps the sample size used in this study was not sufficient to demonstrate any significant difference due to the stimulation treatment (Figure 2). The free activity of lysosomal enzyme in all groups dropped within the first three hr and started to increase after these periods. The non-stressed and stimulated sides had a higher but nonsignificant activity at 12 hr poststimulation than the nonstressed and unstimulated sides. The unstressed but stimulated sides (pH 5.60) tended to have the least amount of free activity at 3 hr poststimulation. Low pH and high carcass temperature condition causes the disruption of the lysosomal membrane and the rapid release of acid hydrolases particularly β-glucuronidase into the muscle tissue (Moeller et al., 1976, 1977).

With the rapid release of β-glucuronidase, the lysosomes were broken down faster and as a result autolytic digestion occurred. Such was the situation at three hr poststimulation; hence the lower activity in the nonstressed and stimulated carcasses. Dutson et al. (1978) observed significantly ($P<.05$) less total activity of both β-glucuronidase and cathepsin C in ovine muscle that was electrically stimulated suggesting that a greater amount of autolysis had occurred in this muscle.

In conclusion, unstressed and electrically stimulated sides had the most rapid rate of pH decline while stressed (stimulated or unstimulated) had the lowest. Stressed sides (stimulated and unstimulated) and control (unstimulated and unstressed) sides were less tender than

unstressed, stimulated sides. Unstressed, stimulated sides had the least variability about the means for tenderness and Instron shear force. This decreased variability is of practical importance. Although the differences were not significant, there were indications that lysosomal enzyme activity might partially be responsible for tenderness due to electrical stimulation. Even if this is true, such contribution by lysosomal enzymes is very small.

Reference

Ashmore, C. R., L. Doerr, G. Foster and F. Carrol. 1971. Respiration of mitochondria isolated from dark-cutting beef. J. Anim. Sci. 33:574.

Bendall, J. R. 1976. Electrical stimulation of rabbit and lamb carcasses. J. Sci. Fd. Agr. 27:819.

Chrystall, B. B. and C. J. Hagyard. 1976. Electrical stimulation and lamb tenderness. N. Z. J. of Agri. Res. 19:7.

Cross, H. R., R. Moen and M. S. Stanfield. 1978. Guidelines for training and testing Judges for Sensory Analysis of Meat Quality. Food Tech. (in press).

Davey, C. L., K. V. Gilbert and W. A. Carse. 1976. Carcass electrical stimulation to prevent cold shortening toughness in beef. N. Z. J. of Agri. Res. 19:13.

Dutson, T. R., G. C. Smith and Z. L. Carpenter. 1978. Lysosomal enzyme distribution in electrically stimulated ovine muscle. J. Food Sci. (submitted).

Gi netto, R. and C. deDuve. 1955. Tissue fractionation studies 4. Comparative study of the binding of acid phosphatase, β-glucuronidase and cathepsin by rat-liver particles. Biochem. J. 59:433.

Gilbert, K. V. and C. L. Davey. 1976. Carcass electrical stimulation and early boning of beef. N. Z. J. of Agri. Res. 19:429.

Gornall, A. G., C. J. Bardawill and M. M. David. 1949. Determination of serum proteins by means of biuret reagent. J. Biol. Chem. 177:751.

Grusby, A. H., R. L. West, J. W. Carpenter and A. Z. Palmer. 1976. Effects of electrical stimulation on tenderness. J. Anim. Sci. 42:253 (abstr.).

Harsham, A. and F. E. Deatherage. 1951. Tenderization of meat. U.S. Patent 2,544,681.

McCollum, P. D. and R. L. Henrickson. 1977. The effect of electrical stimulation on the rate of postmortem glycolysis in some bovine muscles. J. Food Quality 1:15.

Moeller, P. W., P. A. Fields, T. R. Dutson, W. A. Landmann and Z. L. Carpenter. 1976. Effect of high temperature conditioning on subcellular distribution and levels of lysosomal enzymes. J. Food Sci. 41:216.

Moeller, P. A.. P. A. Fields, T. R. Dutson, W. A. Landmann and A. L. Carpenter. 1977. High temperature effects on lysosomal enzyme distribution and fragmentation of bovine muscle. J. Food Sci. 42:510.

Savell, J. W., G. C. Smith, T. R. Dutson, Z. L. Carpenter and D. A. Suter. 1977. Effect of electrical stimulation on palatability of beef, lamb, and goat meat. J. Food Sci. 42:702.

Shaw, F. D. and D. J. Walker. 1977. Effect of low voltage stimulation of beef carcasses on muscle pH. J. Food Sci. 42:1140.

Smith, G. C., T. R. Dutson, Z. L. Carpenter and R. L. Hostetler. 1977. Using electrical stimulation to tenderize meat. Proc. Meat Ind. Res. Conf. 29:147.

Tappel, A. L. 1966. Lysosomes: Enzymes and catabolic reactions In: The Physiology and Biochemistry of Muscle as a Food, Vol. 1, p. 237. ed. E. J. Briskey, R. G. Cassens and J. C. Trautman. The Univ. of Wisconsin Press, Madison.

Tarrant, P. V. and C. Mothersill. 1977. Glycolysis and associated changes in beef carcasses. J. Sci. Fd. Agr. 28:739.

Table 1

Means and (standard deviations) of Instron and palatability ratings[1]

Treatment	n	Sensory Panel Ratings			Instron maximum shear force (kg)
		Tenderness[2]	Juiciness[3]	Connective tissue amount[4]	
Stressed and unstimulated	6	5.3(.85)[ab]	5.4(27)[ac]	6.4(.29)[ab]	6.0(1.40)[a]
Stressed and stimulated	6	5.5(.77)[ab]	4.9(.67)[b]	6.4(.51)[ab]	5.3(1.86)[ab]
Unstressed and unstimulated	6	4.9(1.15)[b]	5.8(.38)[a]	6.2(.31)[b]	5.9(1.51)[a]
Unstressed and stimulated	6	6.0 (.40)[a]	5.0(.30)[bc]	6.8(.42)[a]	5.0(0.92)[b]

[1]Means in the same column having different letters are significantly different ($P<.05$).
[2]Tenderness - 8 = extremely tender, 1 = extremely tough.
[3]Juiciness - 8 = extremely juicy, 1 = extremely dry.
[4]Connective tissue amount - 8 = none, 1 = abundant.

[abc]Means in the same column with different superscripts are significantly different ($P<.05$).

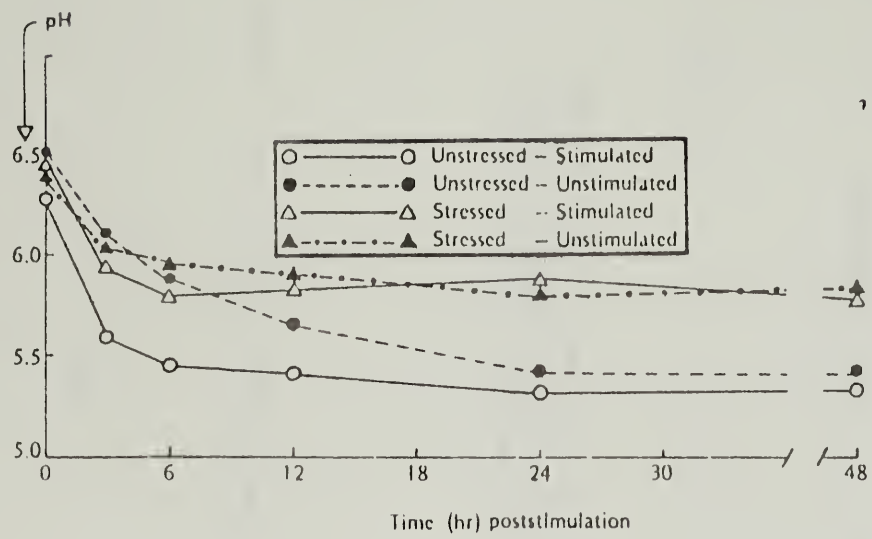

Fig. 1

The effect of electrical stimulation and stress treatment on the rate of pH decline.

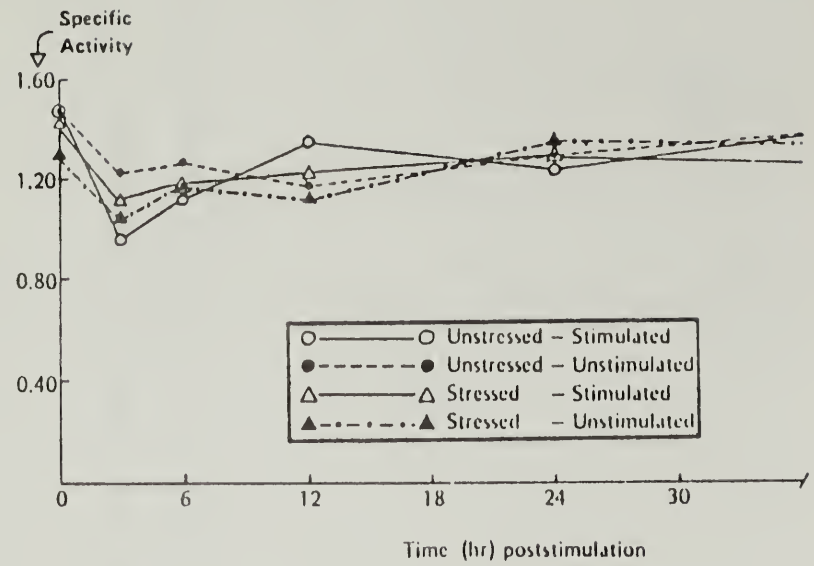

Fig. 2

The effect of electrical stimulation and stress treatment on the release of lysosomal enzyme (β- glucuronidase)

Bacteriological Quality of Ground Beef Prepared from Hot and Chilled Beef Carcasses

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Key Words: Hot boning, ground beef, bacteriological quality

Abstract

The bacteriological quality of ground beef chub packs prepared from "hot" boned beef sides (2 h postmortem) and opposite conventionally chilled sides (24 h at 3 C) were compared at the time of preparation and at 3-day intervals up to 45 days of storage at 0 C. Aerobic plate counts (APC's) in ground beef from "hot" boned beef were either significantly lower or not significantly different from APC's in ground beef from chilled carcasses. There were no significant differences of any practical importance in Most Probable Numbers (MPN's) of coliforms and *Escherichia coli* between "hot" and cold boned ground beef. Ground beef prepared from "hot" boned beef offers tremendous possibilities in energy conservation to the meat industry. The bacteriological quality of ground beef from "hot" boned carcasses does not limit, but rather enhances the feasibility of boning carcasses before chilling.

Introduction

Fabrication of beef carcasses prior to chilling ("hot" boning) has several advantages as an alternative to conventional beef fabrication. Removal of excess fat and bone prior to chilling results in a considerable conservation of energy in terms of total refrigeration input. Additional advantages include reductions in transportation, labor, and investment costs. In recent years researchers investigated the characteristics of "hot" boned bovine muscle (1, 3, 5-10, 12). Most of these studies have been concerned with the effect of "hot" boning on tenderness and eating quality of muscles from Good and Choice grade beef carcasses.

The fabrication of ground beef utilizes a large proportion of the bovine carcass. Little, if any, data have been reported concerning the feasibility of producing ground beef from "hot" processed beef carcasses. Several potential problems include textural changes, color differences and shelf-life. Inordinat bacterial counts in ground beef from "hot" boned carcasses would preclude adoption of the system. The purpose of this investigation was to compare the bacteriological quality and shelf-life of ground beef prepared from "hot" and chilled beef carcasses.

Materials and Methods

Product fabrication

Four USDA Utility grade beef carcasses were utilized in this investigation. The animals were slaughtered and the ground beef was prepared and stored at a commercial beef slaughter and further processing plant. At 2 h postmortem, the top round, strip loin and ribeye cuts were removed from one side of each carcass. At 24 h postmortem, the comparable muscles were removed from the halves which had been chilled at 3 C. The remainder of the meat from the boned carcasses was used immediately for the ground beef fabrication.

The "hot" boned meat was chilled by adding CO_2 snow (0.1 kg CO_2/kg meat) during ground beef fabrication. The "hot" boned meat from the four sides (about 450 kg) was ground through a kidney plate. Two-thirds of the CO_2 snow was added, and the coarsely ground meat was mixed 3 min. The meat was then ground through a 1.27 cm plate, the remainder of the CO_2 snow was added, and the meat was mixed again for 3 min. The final grind was through a .32 cm plate, after which the ground beef was packaged in oxygen-impermeable polyethylene casings to make 5-lb chub packs. The ground beef from the four chilled sides was prepared in the same manner except that CO_2 snow was not used. Fat content of the ground beef was about 21 percent.

Forty-eight ground beef chub packs from the "hot" boned batch and 48 from the cold boned batch were stored at 0 C. Three chub packs from each batch were transported (45 min) to the laboratory for bacteriological analyses after 0, 3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, and 45 days of storage.

Bacteriological analyses

Three locations within each chub pack were sampled aseptically to obtain a 25-g sample that was blended 2 min in 225 ml of sterile Butterfield's phosphate diluent (11). Serial dilutions of the samples were plated in duplicate on 3 sets of plate count agar (Difco Laboratories, Detroit, MI) plates. Aerobic plate counts (APC's) were determined after the duplicate sets of plates were incubated 7 days at 5 C, 3 days at 20 C or 2 days at 35 C.

Most Probable Numbers (MPN's) of coliforms and *Escherichia coli* were determined by methods described in the *Bacteriological Analytical Manual for Foods* (4). All EC broth (Baltimore Biological Laboratory, Cockeysville, MD) tubes showing gas after 24 or 48 h at 45.5 C were streaked onto Levine eosin methylene blue agar (BBL) for detection of typical *E. coli* colonies.

The logarithms (base 10) of the bacterial counts were analyzed statistically by analysis of variance (ANOVA) and Duncan's (2) multiple range test.

Results and Discussion

There were no significant differences in initial APC's (5, 20, or 35 C) between the ground beef prepared from "hot" carcasses and that from chilled carcasses (Table 1). With one exception (APC 5 C at 3 days storage) during the 45-day storage study, the APC's (5, 20, and 35 C) in ground beef from "hot" boned beef were either significantly lower or not significantly different from APC's in ground beef from chilled carcasses.

The bacterial counts of the "hot" boned ground beef did not increase as rapidly during storage as those of the ground beef from chilled carcasses. APC's (5 and 20 C) in the "hot" boned ground beef did not change significantly from the initial counts (0 day) until 30 days of storage at 0 C; APC's (35 C) were significantly higher than initial counts after 33 days. APC's (5, 20 and 35 C) in the ground beef from chilled carcasses increased significantly from the initial counts after 18, 21, and 24 days of storage, respectively.

After 45 days of storage, there were no significant differences in APC's (5, 20, or 35 C) between the "hot" boned and the cold boned ground beef. Both products had reached the end of their microbiological shelf-life; however, the APC's in the "hot" boned product were slightly lower at the end of the storage study than those in the cold boned product. The APC's (5, 20, and 35 C) in the "hot" boned ground beef increased 2.55, 1.78, and 1.65 logs/g, respectively, after 45 days of storage. The APC's (5, 20, and 35 C) in ground beef from chilled carcasses increased 3.08, 2.04, and 1.70 logs/g, respectively, during the same storage period. The appearance and odor of both the "hot" and the cold boned ground beef were acceptable through 42 days of storage; a slight off-odor was detected at 45 days.

MPN's of coliforms and *E. coli* were very low initially and throughout the 45-day storage study (Table 2). There were no significant differences of any practical importance in numbers of these bacteria between "hot" and cold boned ground beef.

The above data indicate that ground beef prepared from "hot" boned carcasses in the manner described in this study has a bacteriological quality and shelf-life equal to or better than ground beef prepared from chilled carcasses. "Hot" boned ground beef as an alternate processing method offers tremendous possibilities in energy conservation to the meat industry and should be pursued accordingly.

Acknowledgements

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Mention of brand names does not imply endorsement by the U.S. Government.

References

1. Dransfield, E., A. J. Brown, and D. N. Rhodes. 1976. Eating quality of hot deboned beef. J. Food Technol. 11:401-407.

2. Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics 11:1-42.

3. Falk, S. N., R. L. Henrickson, and R. D. Morrison. 1975. Effect of boning beef carcasses prior to chilling on meat tenderness. J. Food Sci. 40:1075-1079.

4. Food and Drug Administration. 1976. Bacteriological analytical manual for foods. 4th ed., Food and Drug Administration, Washington, D.C.

5. Gilbert, K. V., and C. L. Davey. 1976. Carcass electrical stimulation and early boning of beef. N. Z. J. Agric. Res. 19:429-434.

6. Gilbert, K. V., C. L. Davey, and K. G. Newton. 1977. Electrical stimulation and the hot boning of beef. N. Z. J. Agric. Res. 20: 139-143.

7. Kastner, C. L., R. L. Henrickson, and R. D. Morrison. 1973. Characteristics of hot boned bovine muscle. J. Anim. Sci. 36:484-487.

8. Kastner, C. L., and T. S. Russell. 1975. Characteristics of conventionally and hot-boned bovine muscle excised at various conditioning periods. J. Food Sci. 40:747-750.

9. Kastner, C. L., D. P. Sullivan, M. Ayaz, and T. S. Russell. 1976. Further evaluation of conventional and hot-boned bovine longissimus dorsi muscle excised at various conditioning periods. J. Food Sci. 41:97-99.

10. Schmidt, G. R., and S. Keman. 1974. Hot boning and vacuum packaging of eight major bovine muscles. J. Food Sci. 39:140-142.

11. USDA. 1974. Microbiology laboratory guidebook. Scientific Services, Animal and Plant Health Inspection Service, USDA, Washington, D.C.

12. Will, P. A., R. L. Henrickson, and R. D. Morrison. 1976. The influence of delay chilling and hot boning on tenderness of bovine muscle. J.

Table 1. Effect of storage at 0 C on APC's in ground beef prepared from "hot" and chilled beef carcasses

Days of storage	APC(5 C)		APC (20 C)		APC (35 C)	
	Hot	Chilled	Hot	Chilled	Hot	Chilled
0	4.30kl[a,b]	3.94lm	5.05g-j	4.96hij	5.13g	5.13g
3	4.17l	3.44m	5.06g-j	4.89ij	5.06g	4.99g
6	4.01lm	3.98lm	5.15g-j	5.06g-j	5.11g	5.18g
9	3.95lm	4.35kl	4.90ij	4.96hij	5.01g	5.22fg
12	4.06l	4.50jkl	5.09g-j	4.92ij	5.27fg	4.99g
15	4.14l	4.47jkl	5.04g-j	4.79j	5.04g	4.92g
18	4.04lm	4.81jk	5.14g-j	5.17ghi	5.19g	5.07g
21	4.27kl	5.06hij	4.78j	5.36fg	4.93g	5.34fg
24	4.06l	5.94d-g	5.01g-j	6.17e	4.99g	5.97de
27	4.26kl	6.14c-f	5.10g-j	6.22e	5.27fg	6.06d
30	4.95ij	5.73efg	5.58f	5.31fgh	5.31fg	5.91de
33	5.60fgh	6.46a-d	5.56f	6.60cd	5.62ef	6.49bc
36	6.52a-d	6.24b-e	6.38de	6.62cd	6.28cd	6.48bc
39	6.75ab	6.70abc	6.83abc	6.75bc	6.74ab	6.68ab
42	5.40ghi	5.66efg	6.70bcd	7.13a	6.71ab	7.03a
45	6.85a	7.02a	6.83abc	7.00ab	6.78ab	6.83ab
Overall average[c]	4.83b	5.28a	5.51b	5.74a	5.53b	5.77a

[a]Each value is the mean $\log_{10}$ count/g of 3 chub packs.

[b]Values for a given APC incubation temperature followed by different letters are significantly ($P \leq 0.05$) different according to Duncan's multiple range test (2).

[c]Overall average values for a given APC incubation temperature followed by different letters are significantly ($P \leq 0.05$) different according to Duncan's multiple range test (2).

Table 2. Effect of storage at 0 C on MPN's of coliforms and *Escherichia coli* in ground beef prepared from "hot" and chilled beef carcasses

Days of storage	Coliforms		*E. coli*	
	Hot	Chilled	Hot	Chilled
0	12b[a,b]	14b	0c	7abc
3	7b	6b	0c	6abc
6	5b	17b	0c	3abc
9	2b	1b	0c	1c
12	9b	1b	9ab	1c
15	6b	0b	0c	0c
18	0b	12b	0c	2bc
21	3b	14b	0c	0c
24	4b	3b	0c	0c
27	22b	4b	0c	4abc
30	8b	10b	0c	10a
33	13b	151a	0c	0c
36	1b	19b	0c	1c
39	0b	5b	0c	5abc
42	0b	5b	0c	4abc
45	3b	4b	0c	1c
Overall average[c]	6a	17a	1b	3a

[a]Each value is the mean MPN/g of 3 chub packs.

[b]Values for a given bacterial classification followed by different letters are significantly ($P \leq 0.05$) different according to Duncan's multiple range test (2).

[c]Overall average values for a given bacterial classification followed by different letters are significantly ($P \leq 0.05$) different according to Duncan's multiple range test (2).

EFFECT OF ELECTRICAL STIMULATION AND SHROUDING METHOD ON QUALITY AND PALATABILTY OF BEEF CARCASSES

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Key Words: Electrical Stimulation, Shrouding tenderness.

Running title: Electrical Stimulation of Beef

Electrical Stimulation of Beef

Summary

In order to evaluate the effect of film overwrap and electrical shock postmortem on carcass quality traits and palatability, 24 sides of beef were assigned to one of 4 treatments: (1) control--shroud and no electrical shock; (2) electrica shock with cloth shroud; (3) no electrical shock with PVC film overwrap; and (4) electrical shock with PVC film overwrap. Carcasses were shocked within 1 hr postmortem and before chilling. Metal pins were placed in the muscles of the round near the Achilles' tendon and in the muscles between the scapula and the thoracic vertebrae. Sides were chilled 18 hr at 2 to 3°C prior to ribbing. Following ribbing and a 15 min. "bloom" time, each side was evaluated for quality and yield grade characteristics and scored for heat ring, color, texture, and firmness. Electrical stimulation had significant positive effects on heat ring decrease, lean color and texture, and tenderness. Film overwrap contributed little over and above the effects of electrical stimulation. These data suggest that electrical stimulation could significantly decrease the incidence of regrades (due to heat ring) and perhaps allow the carcasses to be graded sooner than current practice.

Introduction

Several workers have reported on the effect of electrical stimulation postmortem on beef tenderness (Davey *et al.*, 1976; Savell *et al.*, 1977; Shaw and Walker, 1977; Savell *et al.*, 1978a; and Sorinmade *et al.*, 1978). These results seem to suggest that electrical stimulation accelerated post-mortem pH decline, hastended rigor development and improved tenderness. Dutson *et al.* (1978) and Sorinmade *et al.* (1978) suggested that some portion of the tenderization benefit derived from electrical stimulation, may result from enhanced activity of the autolytic enzyme fractions of muscles in treated carcasses. Savell *et al.* (1978b) suggested that physical disruption of muscle fibers resulting from the massive contractions during stimulation may be a possible mechanism for the tenderness improvement associated with electrical shock.

Accelerated glycolysis in post-mortem muscle could have effects on other quality factors such as color, texture, firmness and color uniformity. Factors affecting meat color have a significant influence upon the meat industry since meat color is an important factor in grading and retail acceptance by the consumer. Savell *et al.* (1978a) monitored the effects of electrical stimulation on quality-indicating traits of beef. Electrically stimulated sides had brighter colored *longissimus* muscles and less severe "heat-ring" formation than control sides. Savell *et al.* (1978a) postulated that the "heat-ring" was due to the differing rate of chill and subsequent pH decline in the muscle resulting in the outside portion of the muscle having a faster rate of temperature decline, higher pH (slower decline) and darker color. It is possible that by adding insulative material to the carcass (such as PVC film) one might be able to slow the rate of chill and accomplish the same result as electrical stimulation. Therefore, the objective of this experiment was to evaluate the effect of PVC film

Experimental

Twenty-four sides of beef were assigned to one of four treatments as outline in Table 1: (1) control - cloth shroud and no electrical shock; (2) electrical shock with cloth shroud; (3) no shock with PVC film overwrap; and (4) electrical shock with PVC overwrap. Sides were shocked within 1 hr. postmortem and before chilling. Metal pins were placed in the muscles of the round near the Achilles' tendon and in the muscles between the scapula and the thoracic vertebrae. Sides received 1.5 amp. of AC (60 HZ) current through the carcass for 3min. with 5-10 sec. duration shocks per minute. Each side was rated for its reaction to shock.

The PVC film overwrap was applied over the cloth shroud extending from just posterior to the sirlion and anterior to the 3rd rib. The film extended completely around the carcass. Sides were chilled 18 hr at 2 to 3°C prior to ribbing. Following ribbing and a 15min "bloom" time, each side was evaluated for quality and yield grade characteristics and subjectively scored for heat-ring (15=none, 1=extreme); lean color (8=light grayish-red, 1=very dark red or purple); lean firmness (8=very firm, 1=very soft);lean texture (8=very fine, 1=very coarse); and degree of fat shrinkage away from lean (15=none, 1=extreme). Temperature was recorded for the longissimus (LD) (12/13th rib interface) at the time of ribbing. A 0.60 cm slice of LD was removed from the rib-end of the loin for pH determination immediately after ribbing. pH was determined as described by Nichols and Cross (1978). After 48 hr post-mortem, a 15 cm section of the posterior end of the rib was removed, frozen and shipped to Texas A&M University (TAMU) for sensory and shear force analysis.

Electrical Stimulation of Beef

Upon arrival at TAMU, two steaks (2.5 cm in thickness) were cut, double-wrapped in polyethylene-coated paper, frozen and stored (-34C) for three weeks. Each steak was removed from the freezer, thawed at 2C for approximately 24hr to an internal temperature of 2-3C and broiled on Farberware broilers to an internal temperature of 70 C (monitored by use of copper Constantan Thermocouples and a recording thermometer). One cooked steak from each side was evaluated by a 10-member trained descriptive sensory panel (according to Cross et al.,(1978) while the second steak was used for shear force determinations by use of the Warner-Bratzler shear force machine (as discribed in the AMSA Guildelines, 1978).

Statistical Analyses

Data were reduced by analysis of variance as outlined by Snedecor and Cochran (1967) and by the mean separation technique of Scheffe' (1959).

Results and Discussion

Mean valves for USDA quality grade characteristics are presented in Table 2. Neither shrouding or shocking treatments had significant effects on USDA quality grade traits. These results are similar to the effects of electrical shock on USDA grade traits as reported by Savell et al., (1978[c]) except that they found significant differences in lean maturity. As indicated in Table 1 paired sides were either assigned to the control (cloth shroud) or film overwrap treatment. In order to compare sides from the same carcass one must compare no shock or electrical shock from the cloth shroud group with their counterparts in the film overwrap group.

Mean valves for lean quality characteristics are presented in Table 3.

Ph, temperature at time of ribbing, and cooking losses were not significantly effected by treatment, although LD temperature tended to be higher in those carcasses that were either shocked or overwrapped with film. Also, cooking losses tended to be slightly higher in shocked carcasses perhaps due to the effect of rate of pH decline on muscle water holding capacity. It appears that LD muscles in all groups had approached their ultimate pH at time of ribbing.

Incidence of heat-ring was signifcantly shock reduced with the electrical shock treatment (Table3). This confirms work reported by Savell et al. (1978[a], 1978[c]). Heat ring formation was reduced slightly in non-shocked carcasses by using the film- overwrap but the combination of shock and film-overwrap appeared to have no additive effects. Lean color was significantly improved with either electrical shock or film-overwrap. The highest ratings for lean color was in the group that received both shock and film, but since the difference between that group and the group receiving electrical alone was small, the practical advantage of using both treatments is not evident. Lean texture was significantly improved when carcasses were electrically stimulated, while film overwrap had no significant effects on lean color.

Two traits normally in common with heat ring are fat pulling or shrinking away from or down below the cut surface of the lean or the lean falling or shrinking below the fat cut surface (Table 3). Electrical shock had no significantly effect on fat shrinkage but film overwrap significantly reduced the fat shrinkage in the unstimulated sides and tended to have the same effects on the shocked sides. Neither film-overwrap nor shock had positive effects on lean shrinkage. In fact, the treatments tended to have slight negative effects on lean shrinkage but even though the means were significantly different, the magnitude of the difference is of little practical concern.

Mean palatability results are presented in Table 4. Steaks from electrically stimulation carcasses were significantly more tender than unstimulated carcasses as indicated by ratings for muscle fiber tenderness, overall tenderness, and shear force. Film-overwrap had no significant effects on tenderness. Amount of panel detectable connective tissue was not significantly affected by treatment. Differences in juiciness were significant (P .05) but the magnitude of the difference was not large enough to be important.

In conclusion, electrical stimulation had significant positive effects on heat-ring decrease, lean color and texure, and tenderness. Film-overwrap contributed little over and above the effects of electrical stimulation.

Literature Cited

AMSA. 1978. Guidelines for cookery and sensory evaluation of meat. Published by the American Meat Science Assoc. in cooperation with National Live Stock and Meat Board. Chicago, Ill.

Cross, H.R., Moen, Ron, and Stanfield, Marilyn S. 1978. Guidelines for training and testing judges for sensory analysis of meat quality. Food Tech. (In press).

Dutson, T.R., Smith, G.C., and Carpenter, Z.L. 1978. Lysosomal enzyme distribution in electrically stimulation ovine muscle. J. Food Sci. (submitted).

Nichols, J. and Cross, H.R. 1978. The effects of electrical stimulation and excision time on pH decline, sarcomere lenght and color in beef muscles. J. Anim. Sci. (submitted).

Savell, J.W., Smith, G.C., Dutson, T.R., Carpenter, Z.L. and Suter, D.A. 1977. Effect of electrical stimulation on palatability of beef, lamb and goat meat. J. Food Sci. 42:702.

Savell, J.W., Smith, G.C. and Carpenter, Z.L. 1978a. Effect of electrical stimulation on quality and palatability of light-weight beef carcasses. J. Anim. Sci. 46. (In press).

Savell, J.W., Dutson, T.R., Smith, G.C. and Carpenter, Z.L. 1978b. Structural changes in electrically stimulated beef muscle. J. Food Sci. 43:(In press).

Savell, J.W., Smith, G.C. and Carpenter, Z.L. 1978c. Beef quality and palatability as affected by electrical stimulation and color aging. J. Food Sci. (In press).

Scheffe', Henry 1959. The Analysis of Variance. John Wiley and Sons, Inc. New York, N.Y.

Shaw, F.D. and Walker, D.J. 1977. Effect of low voltage stimulation of beef carcasses on muscle pH. J. Food Sci. 42:1140.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical Methods (6th Ed.) Iowa State University Press, Ames.

Sorinmade, S.O., Cross, H.R., and Ono, K. 1978. The effect of electrical stimulation on Lysosmal enzyme activity,pH decline and beef tenderness. 24 European Meats Conf. Kulmbach, Germ. (accepted)

LE 1 EXPERIMENTAL DESIGN.[a]

Treatments	Treatments			
	Shroud (control)		Shroud and Film overwrap	
Electrical Shock	1 left 2 " 3 "	7 left 8 " 9 "	1 right 2 " 3 "	7 right 8 " 9 "
No Electrical Shock	4 left 5 " 6 "	10 left 11 " 12 "	4 right 5 " 6 "	10 right 11 " 12 "

1-12 represents carcass numbers

TABLE 2 [illegible] carcass traits for shroud, film and shock treatments.

Trait	Shroud (control)		Shroud and Film overwrap	
	N S[a]	E S[b]	N S[a]	E S[b]
Fat thickness over ribeye, cm	.18*	.37	.16	.38
Ribeye area, cm^2	78.58	77.74	77.23	77.29
Marketing	SM^-	SM	SL^+	SM
Lean maturity	A^-	A	A	A
USDA yield grade	2.0	2.6	2.0	2.6
USDA quality grade	C^-	C^-	G^+	C^-

a NS = not stimulated
b ES = electrically stimulated
* All means were not significantly different ($P<.05$)

TABLE 3 Average quality traits for shroud, film and shock treatments.

Trait	Shroud (control)		Shroud and Film overwrap	
	N S[a]	E S[b]	N S[a]	E S[b]
pH (raw)	5.88[i]	5.75[i]	5.70[i]	5.77[i]
Temperature, °C	1.83[i]	3.50[i]	3.78[i]	5.23[i]
Cooking losses, %	29.37[i]	31.74[i]	28.72[i]	30.23[i]
Heat ring [c]	12.33[i]	6.50[j]	10.33[i]	6.33[j]
Lean firm [d]	6.17[i]	5.83[i]	6.17[i]	5.83[i]
Lean color [e]	2.83[j]	4.17[i]	4.33[i]	5.17[i]
Lean texture [f]	4.50[j]	6.67[i]	4.67[j]	6.67[i]
Fat shrink [g]	3.50[j]	3.50[j]	6.33[i]	4.83[ij]
Lean shrink [h]	5.67[i]	2.17[j]	3.33[ij]	2.18[j]

a NS = non-stimulated
b ES = electrically stimulated
c heat ring 15 = extreme and 1 = none
d lean firm 8 = very firm and 1 = very soft
e lean color 8 = light grayish-red and 1 = very dark red
f lean texture 8 = fine and 1 = very coarse
g fat shrink 15 = none and 1 = extreme
h lean shrink 15 = none and 1 = extreme
ij means in the same row with different superscripts are significantly different ($P<.05$)

TABLE 4 Average sensory panel and shear valves for shroud, film and shock treatments.

Trait	Shroud (control)		Shroud and Film overwrap	
	N S[d]	E S[e]	N S[d]	E S[e]
M.F. Tenderness[a]	3.78[h]	4.89[fg]	4.04[gh]	4.98[f]
O.A. Tenderness[a]	3.79[h]	4.90[fg]	4.09[gh]	4.99[f]
Connective tissue AMT.[b]	5.82[f]	6.26[f]	5.82[f]	6.38[f]
Juiciness[c]	4.70[fg]	5.02[f]	4.42[g]	4.76[f]
Shear force, kg.	7.03[f]	5.37[g]	7.04[f]	5.77[g]

a. Muscle fiber tenderness and overall tenderness 1 = extremely tough and 8 = extremely tender.

b. Connective tissue amount 1 = abundant and 8 = none

c. Juiciness = 1 = extremely dry and 8 = extremely juicy

d NS = not stimulated

e ES = electrically stimulated

f-h = Means in the same row with different superscripts are significantly different ($P < .05$).

PHYSICAL, CHEMICAL & SENSORY PROPERTIES OF GROUND BEEF PREPARED FROM HOT AND CHILLED BEEF CARCASSES[1]

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Key Words: Hot Boning, ground beef, palatability

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Introduction

More than 40 million bovines are presently slaugtered in the U.S. each year. Vast amounts of energy are currently being used to process, transport and market this volume of meat. Alternate processing methods such as hot-boning offers tremendous possibilities in energy conservation and increased marketing efficiency. By the year 1980, about 50% of the beef slaughter will be consumed as ground beef (Pietraszek, 1975).

The ground beef industry represents a large proportion of the total energy requirements of the meat industry. Little, if any, data has been reported concerning the feasibilty of producing ground beef from hot processed beef carcasses. Several potential problems include textural changes, color differences and shelf-life. In order for the ground beef segment to be viable the hot processing of steak and roast cuts from the same carcasses must also be possible. Much of the hot processing data in the literature has concentrated on the palatability of steaks and roasts from USDA Good and Choice carcasses (Kastner et al., 1973; Falk et al., 1975 and Schmidt and Gilbert, 1970. No data has been reported on the effect of hot boning of mature (> 4 yrs) beef carcasses on shelf-life and palatability. The steak and roast cuts from these carcasses are usually tenderized by mechanical and enzymatic methods. This labatory is currently investigating the effects of hot boning on the physical, chemical and microbiol properties of ground beef, and steaks and roasts from mature beef carcasses. This manuscript will deal with the palatability and cookery yields of the ground beef segment of the study.

METHOD 2.- Hot Processed

Method 2 differed from method 1 only in the number of grinds and the manner in which the CO_2 Snow was added. The lean and fat was passed through a kidney plate, mixed 3 to 4 min; passed through a 1.27 cm plate, mixed 3 to 4 min and passed through a 0.32 cm plate for the final grind. CO_2 Snow was added at a ratio of 1:10 with two-thirds added during the first and one-third during the second mix.

METHOD 3.- Hot Processed

Method 3 differed from method 2 only in the amount of CO_2 Snow added and the absence of choice plates. Since no chilled choice plates were added the ratio of CO_2 Snow to meat was increased to 1.5 to :10. Also the carcasses used for this method were slightly fatter than those used in methods 1 and 2 in order for the final fat content to be $21 \pm 2\%$.

PATTIES.

Ground beef from all formulations were formed into 113 g (4 oz) patties using a FORMAX model 26 patty machine. Patties were stacked (10 per stack) boxed and frozen/ stored at $-10^{o}C$ for 5 days before shipment to Beltsville, MD for analysis.

TRAINED PANEL.

A 10-member descriptive attribute panel, trained by the procedures of Cross et al.(1978a) and AMSA (1978), evaluated samples from each treatment in a total of 10 sessions; six samples were evaluated per session and each treatment was replicated 5 times. The panel rated each sample for differences in tenderness, juiciness, connective tissue amount and ground beef flavor intensity with 8= extremely tender, juicy, no detectable connective tissue, and intense and 1= extremely

tough, dry, abundant connective tissue and bland in ground beef flavor.

COOKERY AND PRESENTATION TO PANEL.

Frozen patties were broiled on electric Farberware grills (model 450-A) to an approximate internal temperature of 60°C. Temperature was monitored during cooking with teflon-coated iron/constantan thermocouples. Beef patties prepared from hot-boned beef carcasses required approximately 11 minutes total cooking time while the control patties required 13 min. Frozen and cooked weights were obtained in order to calculate total cooking losses. Four patties were prepared for each session replicate. Each patty was sectioned into 6 pieces and two of the 24 pieces (4 patties) were randomly assigned to each panelist. The samples were served as warm as possible to the panelists as described in ASMA (1978). After sectioning, the pieces were pictorially scored for degree of doneness (color photographs with 1= well done and 8= rare) by a trained laboratory technician.

SHEAR FORCE.

Ten patties from each method/batch group were used for determination of Instron shear force according to procedures outlined by Cross et al (1978b), The single-blade shear device 2.54 cm squares. Four squares were obtained from each patty, thus each mean value for method/batch represents 40 observations.

PHYSICAL AND CHEMICAL.

Height and diameter measurements were obtained on the ten frozen and cooked patties used for the Instron. Percent fat and moisture was determined on raw and cooked patties according to AOAC procedures. PH was determined on ten frozen, thawed and cooked patties from each treatment using the procedure described by Nichols and Cross, (1978).

RESULTS AND DISCUSSION

Data in tables 2-4 combines methods of processing to allow a direct comparison of sensory, physical and chemical properties of ground beef prepared from hot verses chilled beef. Mean palatability and shear force values are presented in table 2. Ground beef patties prepared from hot processed beef were significantly ($P < .05$) more tender (panel) and juicy than patties prepared from chilled beef. Differences in shear force were not evident although the trends were similar to those established by the trained panel. As might be expected, treatment had no significant effects on amount of connective tissue or flavor intensity.

Total cooking loss was significantly less in the hot processed patties when compared to the chilled patties (table 3). The differences were quite large (33.85 vs 41.06%) and of considerable practical importance. These differences in cooking losses were reflected in ratings for juiciness (table 2). Hot processed patties had significantly less configuration change and diameter than chilled patties. Percent change in height and thaw loss was not significantly affected by treatment. In an institutional use situation the most important configuration parameter would be diameter in order to keep a constant area of the bun covered.

Since the hot boned beef was processed prerigor the possibility existed for some thaw rigor to occur. In this study the possibility was small because the patties were frozen over a 10-20 hr period. Muscle PH was determined on the frozen, thawed and cooked samples to determine if the sample had reached its ultimate PH prior to freezing. This data is presented in table 4. As expected, there were

no significant differences in PH between hot and chilled patties. This is also reflected in the lack of significant differences in thaw loss (table 3). If the hot processed patties had been frozen cryogenically thaw rigor might have been a problem. Research is in progress to investigate these possibilities. Percent fat and water did not differ significantly in the raw patty (table 4) and percent fat was not different in the cooked patty. Percent water differed significantly in the hot and chilled cooked patty. This, of course, was illustrated in the differences in cooking loss (table 3). One might expect that a patty from hot processed beef might contain more water in the raw as well as the cooked state. If this were the case, one could expect less nutrients from a certain size Hot processed patty. Such was not the case, as shown by the data in table 4. Undoubtedly, the hot and chilled patty are quite similar as to composition in the raw state but the chilled patty loses more water during cooking. This water loss results in lower juiciness and tenderness ratings and possibly more patty left on the plate.

An evalvation of the effect of method of grinding on sensory, physical and chemical properties is presented in table 5 and 6. Data for sensory and shear is outlined in table 5. Method of grinding had no significant affect on any palatability trait except flavor intensity. Patties prepared by method 3 were less intense in flavor than methods 1 and 2. This difference was probably a reflection of the absence of choice plates in the formulation rather than method of grinding. In any case, the difference was probably too small to be of practical

importance. It is interesting to note patties prepared from hot boned beef were more tender and juicy than patties prepared from chilled beef regardless of method of grinding.

Percent total cooking loss height change, thaw loss and degree of doneness were not significantly affected by method of grinding (table 6). Percent diameter change was greatest in patties prepared by method 1 (Kidney plate x 0.32 cm). It is difficult to explain why the double grind should result in more diameter shrinkage than the triple grinds. Mean values frozen, and thawed and cooked PH; and raw and cooked fat and water were not significantly affected by method of grinding (data not presented).

In conclusion, it is quite evident from this data that beef patties can be prepared from hot processed beef that are equal to or superior to patties prepared from chilled beef in palatability, physical and chemical properties. Patties prepared from hot processed beef were significantly more tender and juicy and loss much less water during cooking.

LITERATURE CITED

American Meat Science Association. 1978. Guidelines for Cookery and Sensory Evaluation of Meat. published by AMSA and the National Livestock and Meat Board, Chicago, Ill.

Cross, H.R., Moen, R. and Stanfield, Marilyn S. 1978.[a] Guidelines for training and testing judges for Sensory analysis of Meat quality. Food Technologists. (In press).

Cross, H.R., Stanfield, Marilyn S. and Franks, W.J., Jr. 1978[b] Objective Measurements of texture in ground beef patties. J. Food Science (In press).

Falk, S.N., Henrickson, R.L. and Morrison, R.D. 1975. Effect of boning beef carcasses prior to chilling on meat tenderness. J. Food Science 40.

Kastner, C.L., Henrickson, R.L., and Morrison, R.D. 1973. Characteristics of hot boned bovine muscles. J. Animal Science 36: 484.

Nichols, J. and Cross, H.R. 1978. The effects of electrical stimulation and excision time on PH decline, sarcomere length and color in beef muscles. J. Animal Science (Submitted).

Pietraszek, G. 1975. Mechanical deboning is here. The National Provisioner 172 C 14.

Schmidt, G.R. and Gilbert, K.V. 1970. The effect of muscle excision before the onset of rigor mortis on the palatability of beef. J. Food Technology 5:331.

TABLE 1. Design

	PREPARATION METHODS[a]							
	1 (Hot) Batch		2 (Hot) Batch		3 (Hot) Batch		Control (Chill^{2}D) Batch	
	A	B	A	B	A	B	A	B
N= 4 sides per batch								

[a]Method 1: Kidney plate x 0.32 cm final.

Method 2: Kidney plate x 1.27 cm x 0.32 cm final.

Method 3: No choice plates; Kidney plate x 1.27 cm x 0.32 final.

Control: 1.27 cm x 0.32 final.

TABLE 2. Mean palatability and shear force values for ground beef prepared from hot and chilled muscle.

	TYPE OF PROCESSING	
TRAIT	HOT	CHILLED
Tenderness[a]	5.69[e]	5.22[f]
Connective tissue[b]	4.26[e]	4.38[e]
Juiciness[c]	5.47[e]	4.75[f]
Flavor intensity[d]	5.23[e]	5.27[e]
Max. Shear force, kg.	10.99[e]	11.96[e]

a. 8 = extremely tender and 1 = extremely tough.

b. 8 = none and 1 = abundant amount.

c. 8 = extremely juicy and 1 = extremely dry.

d. 3 = extremely intense and 1 = extremely bland.

n = 30 observations per mean.

ef: means in the same row with different superscripts are significantly different ($P < .05$).

TABLE 3. Cooking properties of ground beef prepared from hot and chilled muscle.

	TYPE OF PROCESSING	
TRAIT	HOT	CHILLED
Total cooking loss, %	33.85[b]	41.06[c]
Degree of doneness[a]	2.32[b]	2.45[b]
Diameter change, %	14.93[b]	19.32[c]
Height change, %	16.06[b]	14.04[b]
Thaw loss, %	5.39[b]	6.21[b]

a 8 = rare and 1 = well done

bc means in the same row with different superscripts are significantly different ($P < .05$).

TABLE 4. Chemical properties of ground beef prepared from hot and chilled muscle.

	TYPE OF PROCESSING	
TRAIT	HOT	CHILLED
PH raw, frozen	5.52[a]	5.46[a]
PH raw, thawed	5.37[a]	5.32[a]
PH cooked	5.50[a]	5.46[a]
H_2O, raw, %	62.11[a]	62.29[a]
fat, raw, %	20.01[a]	19.55[a]
H_2O, cooked, %	52.10[a]	48.60[b]
Fat, cooked, %	21.10[a]	21.80[a]

ab means in the same row with different superscripts are significantly different ($P < .05$).

TABLE 5. Comparison of palatabilty traits of three systems of grinding hot, processed beef.

TRAIT	HOT PROCESSED BEEF METHOD OF GRINDING[a] 1	2	3	control chilled
Tenderness[b]	5.48[f]	5.90[f]	5.68[f]	5.22
Connective tissue[c]	4.06[f]	4.48[f]	4.24[f]	4.38
Juiciness[d]	5.36[f]	5.61[f]	5.43[f]	4.75
Flavor intensity[e]	5.39[f]	5.37[f]	4.93[g]	5.27
Max. Shear force, kg.	11.19[f]	10.35[f]	11.38[f]	11.96

[a]1 = kidney plate x 0.32cm plate.
2 = kidney plate x 1.27cm plate + 0.32cm plate.
3 = kidney plate x 1.27cm plate + o.32cm plate (no Choice plates added as in 1 and 2).
[b]8 = extremely tender and 1 = extremely tough.
[c]8 = none and 1 = abundant amount.
[d]8 = extremely juicy and 1 = extremely dry.
[e]8 = extremely intense and 1 = extremely bland.
[fg]Means in the same row with different superscripts are significantly different (P <.05).

TABLE 6. Comparison of Cooking properties of three systems of grinding hot beef.

TRAIT	HOT PROCESSED BEEF METHOD OF GRINDING[a] 1	2	3	control chilled
Total cooking loss, %	36.48[c]	35.04[c]	30.02[c]	41.06
Degree of doneness[b]	2.05[c]	2.60[c]	2.30[c]	2.45
Diameter change, %	16.53[c]	14.17[d]	14.08[d]	19.32
Height change, %	18.24[c]	20.76[c]	9.17[c]	14.04
Thaw loss, %	5.47[c]	6.23[c]	4.48[c]	6.21

b 8 = rare and 1 = well done.

cd means in the same row with different superscripts are significantly different ($P < .05$).

The Effects of Electrical Stimulation and Early Post-Mortem Muscle Excision on pH Decline, Sarcomere Length, and Color in Beef Muscles

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Running head: Electrical Stimulation and pH Decline

Key words: electrical stimulation, hot-boning, pH decline, sarcomere length, muscle color

Introduction

Fifty percent of the energy used in beef plant refrigeration could be conserved if hot-boning were incorporated into an in-line process (Meat Industry, 1977). Savings in energy would stem from the lack of necessity to chill inedible fat and bones while expediting the chilling of the edible lean portions. Meat quality, however, may be affected since hot-boning can toughen some muscles.

Locker (1958) concluded that tenderness is affected by the degree of muscular contraction experienced in early post-mortem. Muscles which are not allowed to contract during rigor either by physical (McCrae, et al., 1971) or skeletal (Herring et al., 1965; Hostetler et al., 1973) restraint are more tender than muscles free to contract. These findings are supported by differences in sarcomere length. Muscles hot-boned prior to rigor onset have been removed from all restraint and are thus free to contract. In addition to normal shortening, meat may toughen appreciably due to "cold shortening" (Locker and Hagyard, 1963) when stored at lower temperatures. Bendall (1977) stated that cold shortening does not occur at a pH of 6.0 or below.

Electrical stimulation of prerigor meat has been proven to decrease the necessary time of rigor mortis (deFremery and Pool, 1959; Hallund and Bendall, 1965; Davey, et al., 1976; Grusby, 1976; McCollum and Henrickson, 1977). Therefore, combining electrical stimulation and hot-boning seems logical.

Meat color is affected by pH and temperature conditions of prerigor meat (Cook, 1968) and, therefore, may be affected if beef carcasses are electrically stimulated and the rate of pH decline altered.

The purpose of this study was to demonstrate the effects of electrical stimulation combined with hot-boning on: (1) pH decline, (2) sarcomere length, and (3) color of longissimus dorsi (LD) and semimembranosus (SM) muscles.

Materials and Methods

Eighty sides from forty Hereford and Angus steers (average USDA yield grade = 3.4 average USDA quality grade = high Good) were randomly assigned to one of twenty treatment cells. Treatments were: (1) electrically stimulated vs. nonstimulated, (2) muscle excision (hot-boning) at 1,2, or 4 hrs. post-mortem, and (3) storage according to one of three storage methods. These storage methods were: (1) immediate freezing at -30 C following excision, (2) chilling for 6 hrs. at 3 C following excision and prior to freezing at -30 C, and (3) chilling for 5 days at 3 C. In the text, these storage methods will be referred to as storages I, II, and III, respectively. Eight control sides (four being stimulated, four not being stimulated) were chilled for 48 hrs. prior to muscle excision.

Carcasses designated to be electrically stimulated were treated at approximately 1 hr post-mortem with a continuous 1 amp current (AC-60 cycle) for two minutes. Since current was applied in terms of constant amperage, voltage ranged from approximately 140 to 200 volts. Copper electrodes were used to conduct the current with one being inserted in the neck and the other in the posterior region of the Achilles' tendon. Carcasses were held at 5 C prior to removal of the SM and a portion of the LD muscles. The SM muscle was removed by severing the connective tissue attachments to the semitendonosus, biceps femous, and adductor muscles

and cutting 1.3 cm above and parallel to the ischium. The LD muscle was removed by severing attachments to the spinal and transverse processes between the midpoints of the second and sixth lumbar vertebrae. The LD and SM muscles were vacuum-packaged in a Multivac (Type AG 500) in appropriate size Cryovac B620 bags and dipped in a hot water bath (approximately 100 C) for 2 to 3 seconds.

pH Determination

Five .64 cm slices were taken from the posterior end of the LD muscle. One section was immediately frozen and stored in liquid nitrogen at the time of excision while the remaining four were vacuum packaged and stored in close proximity of the LD muscle. At 6, 10, 21, and 30 hrs. post-mortem, one of the remaining samples was unwrapped and frozen and stored in liquid nitrogen. Since the pH should be at its ultimate value at 48 hrs excision time, pH decline data are not available for control muscles. For pH determination, 1 gram representative of the cross-sectional area of the LD muscle was slurried in 10 mls. of .05 M iodoacetate solution. A Brinkman polytron set at maximum speed for 20 seconds was used to slurry the sample and the pH of the resulting solution was measured with a Beckman Zeromatic SS-3.

Sarcomere Length

Sarcomere length was determined with a Metro Neon Laser using a procedure similar to that of Ruddicks and Richards (1975). Four 1 gram samples were removed from each of the LD and SM muscles at the time of excision (initial length) and after five days of the assigned storage (final length). The samples were stored in a 2.5% glutaraldehyde solution for 2 hrs followed by storage in the same solution with

.025 KCL for 24 hrs. One fiber from each of the 4 samples was separated from the bundle, placed between two glass cover slips, and subjected perpendicular to the laser beam. The distance between the zero and first order diffraction bands were measured and converted to the appropriate unit of microns.

Appearance Evaluation

On the fifth day of storage, the LD and SM muscles treated according to Storage III (3 C for five days) were unwrapped and cut into 3.2 cm thick steaks. The steaks were allowed to oxygenate for 45 minutes and fat was trimmed to no more than 1.0 cm. The fourth steak from the anterior end of each muscle was placed on Molifoam packaging trays (T-02SO and T-16SO for the LD and SM, respectively) wrapped in polyvinyl chloride film (no. 5601) and heat sealed. The packaged steaks were placed in a retail display case at 3 C and exposed to 88-92 ft/candles of incandescent light for 5 days. The light was turned off for 10 hrs per day.

A six-member trained panel was instructed to evaluate the color, fat cover, and color uniformity of the LD and SM steaks. Each panelist scored the steaks once each day for the five-day period. The panelists were trained to evaluate color uniformity on a basis of the percent of the surface area which was one or more units different for muscle color than the dominant color of the steak. The steaks were randomly rearranged in the display case each day.

Prior to wrapping in polyvinyl chloride film on day 1, the percent reflectance of red color for the LD and SM steaks was measured by a Photronic percent reflectance meter (model TC). The Photronic meter

was standardized to 100% reflectance on a solid white magnesium oxide block. The reflectance reading was taken in the approximate center of the steak. After the five day display a second reflectance measurement was taken.

Statistical Analysis

Data for pH decline was transformed and analyzed as pH vs. log of post-mortem time since this conversion would yield the most sensitive comparison of slopes. The ANOVA procedure was used on the transformed data to test the effects of electrical stimulation, excision time, and storage method on the pH decline. In addition, the orthogonal polynomial contrasts of excision time and post-mortem time were tested for significance within each storage by stimulation treatment combination.

For subjective panel color determination, the ANOVA procedure was used to test for effects of electrical stimulation, excision time, days, all relevant interactions, and blocks (replicates were blocked on a basis of weight in order that possible differences due to weight or finish of the animal could be removed). Scores from the six panelists were combined to give one mean per steak per day. The error term of the ANOVA is, therefore, based on the within variation of the four observations per treatment group. The Photronic objective evaluation was analyzed the same except that blocks were not considered and only day 1 (initial) and day 5 (final) were included in the model.

Sarcomere length was analyzed for possible effects of electrical stimulation, excision time, storage method, relevant interactions, and blocks on initial length, final length, and differences between initial and final length. Since cold shortening is reported to significantly

affect sarcomere length, storage methods were directly compared with orthogonal comparisons both independently and nested within electrical stimulation treatment and excision time.

Results and Discussion

Graphs for pH decline are shown in Figures 1, 2, and 3 for Storages I, II, and III, respectively. These data were statistically analyzed as pH *vs.* the log of time but values plotted in Figures 1, 2, and 3 are original numerical form.

Initial pH values for electrically stimulated and nonstimulated LD muscles in Storage I (Figure 1) were relatively close. As opposed to nonstimulated muscles, however, pH of electrically stimulated LD muscles fell quickly between initial and 6 hours and subsequently the curvilinear effect of post-mortem time was significant ($P<.01$). A rapid initial fall in pH was not observed for the nonstimulated muscles. Therefore, for nonstimulated muscles, the -30 C storage was capable of slowing the pH decline since the muscle tissue could begin to freeze while the pH was still relatively high. This occurence is manifested by the significance ($P<.05$) of the excision time x post-mortem time interaction. In contrast to electrically stimulated LD muscles, the earlier nonstimulated muscles were hot-boned, the slower the decline and the higher the pH values were for each sampling period. In fact, the pH at 30 hours for nonstimulated muscles hot-boned at 1 or 2 hrs (approximately 5.7) is the highest of any treatment combination. It may be concluded that although excision time affected the decline of both electrically stimulated and nonstimulated LD muscles, electrical stimulation caused such a rapid drop that possible effects due to the

interrelationship of excision time and the -30°C storage temperature were minimized. This contrasts the results for nonstimulated LD muscles.

In Storage II (Figure 2), the curvilinear effect of post-mortem time was again significant ($P<.01$) for electrically stimulated LD muscles and nonsignificant for nonstimulated muscles. Also, the excision time x post-mortem time interaction was again nonsignificant for the electrical stimulation treatment but statistically significant ($P<.05$) for nonstimulation. Apparently, the quick initial drop in pH following electrical stimulation again reduced the effects of excision and storage in comparison to nonstimulated LD muscles. For Storage II, LD muscles excised at 1, 2, and 4 hrs entered the -30 C freezer at 7, 8, and 10 hrs, respectively. For the 1 hr hot-boned muscles, entry into the freezer at 7 hrs decreased the decline between 6 and 10 hrs post-mortem compared to what could have been expected. This effect was greater for electrically stimulated LD muscle since non-stimulated muscles declined most appreciably between 6 and 10 hrs post-mortem. LD muscles electrically stimulated and hot-boned at 2 or 4 hrs were near the ultimate pH at the time of freezer entry (8 and 10 hrs, respectively) and subsequently this occurrence had little if any effect on the pH decline. In contrast to Storage I (-30 C), nonstimulated and electrically stimulated LD muscles were similar in pH at 30 hrs for all three excision times.

In contrast to freezing, the excision time x post-mortem time interaction was significant ($P<.05$) for electrically stimulated LD muscles stored at 3 C (Figure 3). Therefore, the pH of electrically stimulated LD muscles declined more rapidly the longer the muscle

remained intact on the carcass prior to excision. Similar to Storages I and II, the excision time x post-mortem time interaction was significant (P<.0001) for nonstimulated LD muscles. Furthermore, the curvilinear effect of post-mortem time was again significant (P<.0001) for the electrical stimulation treatment but nonsignificant for non-stimulation. Once again, these results indicate a faster decline to the final pH following electrical stimulation and the tendency of lower storage temperatures to retard the decline of nonstimulated muscles. Davey et al. (1976) concluded that the ultimate pH of beef muscle could be reached as early as 5 hrs following electrical stimulation. These data support Davey et al. (1976) in that electrically stimulated muscles excised at 4 hrs and chilled (Storages II and III, only) were at the ultimate pH at 6 hrs in spite of storage for 2 hrs at 3 C.

Mean values for initial and final sarcomere length of LD muscles are listed in Table 1. In agreement with Savell et al. (1977) and Savell et al. (1978), electrical stimulation did not affect sarcomere length. In addition, excision time and storage method did not significantly affect sarcomere length. LD muscles hot-boned at 1 hr appear to have shortened less following electrical stimulation, however, the excision time x stimulation interaction for all groups was nonsignificant. Both electrically stimulated and nonstimulated LD muscles excised at 4 hrs were near a pH of 6.0 at the time of excision, however, this group did not differ for initial, final, or change in length. Excluding all treatment classifications and comparing all initial vs. all final measurements, sarcomere length significantly (P<.01) decreased .07 microns.

Mean values for inital and final sarcomere length of SM muscles are listed in Table 2 similar to the findings for LD muscle, significant differences did not occur due to electrical stimulation, excision time, or storage method. In contrast to LD muscles, however, the sarcomere length of SM muscles did not decrease when all initial vs. all final lengths were compared.

Cook (1968) found that color development of ovine muscle homogenates was determined by buffer pH, incubation temperature, and the interaction of these two effects. Manifestations of rigor mortis other than pH decline did not affect the ultimate color of the homogenates. Ashmore et al. (1972) explained this pH dependance by means of the oxygen consumption rate of the mitochondrial respiration. At higher pH values, oxygen consumption by mitochondria at the surface of meat inhibits the permeation of oxygen into the tissue and thereby reduces the conversion of myoglobin to oxymyoglobin. Lower pH values inhibit mitochondrial activity (probably enzymatic inhibition) thus oxygen will penetrate the meat surface and bind to the myoglobin molecule. Post rigor oxygen consumption by mitochondria as affected by pH greatly explains color development in the extreme case of dark-cutting beef. The combination of high temperature and low pH in the prerigor state greatly affects meat color as evidenced in pale, soft, and exudative pork. Locker and Daines (1975) found that muscles entering rigor at 37 C as opposed to lower temperatures were softer and paler in color. These conclusions are supported by the findings of Cook (1968). In the postrigor state, lower temperatures favor the oxygenation of myoglobin upon exposure since mitochondrial respiration is impaired with decreasing temperatures

(Bendall, 1972; Bendall and Taylor, 1972; DeVore and Solberg, 1974).

Kastner et al. (1973) reported differences for objective color measurements for hot-boning at 2, 5, or 8 hrs post-mortem vs the 48 hrs cold-boned controls. In this study subjective evaluation differences occurred for cuts hot-boned at 2 hrs post-mortem vs control. Henrickson (1974) reported similar findings for hot-boning at 3 hours post-mortem. The method of subjective evaluation used in these studies did not indicate whether the hot-boned cuts were lighter or darker, or more or less desirable.

Table 3 lists the mean values for color uniformity, fat cover, muscle color, and percent reflectance for the red color (Storage III, only) for LD and SM muscles. As expected, days significantly ($P<.001$) affected all four appearance parameters for both muscles. Proceeding from Day 1 to Day 5 the LD and SM muscles became darker and increased in percent reflectance due to dessication (Pirko and Ayres, 1959). In addition, the muscles became less uniform in color and the fat became more discolored.

Neither electrical stimulation nor excision time significantly affected fat cover or percent reflectance for either muscle. Electrical stimulation of the prerigor beef carcasses did not affect either the muscle color or color uniformity of the LD or SM muscles. Therefore, it might be concluded that an accelerated pH decline alone does not affect the ultimate meat color of beef.

Excision time demonstrated a substantial effect on both the color and color uniformity of the SM but not the LD muscle. This result may be due to differences in temperature gradients during chilling.

The LD has lesser transverse surface area and is located near the surface of the carcass while the SM has a much larger transverse surface area and extends deeper into the carcass. Therefore, the SM muscle is subject to a more severe temperature gradient. Tarrant and Mothersill (1977) demonstrated that the rate of post-mortem glycolysis varied with depth in the carcass. The pH decline was faster with increased depth into the carcass due to the higher temperatures maintained internally. These findings help to explain the following results.

Excision time significantly ($P<.05$) affected the decline for color uniformity of the SM muscle (Figure 4). A higher color uniformity score was maintained over the five day display period the earlier the muscle was hot-boned and is attributable to the more uniform chill through the muscle produced by earlier exposure to the 3 C storage. Apparently, the longer the delay till excision the more dramatic effect of a high temperature and low pH combination on the innermost parts of the muscle. For the 4 hr hot-boned and 48 hr control, the portion of the SM muscle located adjacent to the femur deep in the carcass was very light pink in color and appeared somewhat exudative. The color uniformity of the 48 hr control was rated similar to muscles excised at 1 or 2 hrs on Days 1 and 2 but decreased sharply on the third day of display. This initially high rating for color uniformity was due to the overall initial lightness in color (Figure 5). The sharp decrease on the third day could be attributed to protein denaturation during rigor mortis and subsequent drip loss of the inner portion of the muscle combined with darkening of the outer portions due to dessication. This would explain the significance ($P<.001$) of the excision time x Day interaction on SM color uniformity. Beginning at Day 3 (Fig. 4) differences in color uniformity between 4 and 48 hrs

excision times vs 1 or 2 hrs are of large enough magnitude to be of practical importance in consumer selection.

Differences in muscle color (Figure 5) for excision times were not of as great a consequence as those for color uniformity but agree with previous studies cited in this paper. Muscles excised at 1 or 2 hrs post-mortem were darker in color compared to the 4 hr hot-boned or the 48 hr control. This result would be expected if higher temperatures maintained during the pH decline did impair future mitochondrial activity. Similar to the color uniformity the muscle color of the control decreased sharply after Day 2 and subsequently the excision time x Day interaction was again significant (P .05).

Summary

Electrical stimulation of prerigor beef carcasses produces a rapid initial drop in pH of LD muscles excised and vacuum-packaged at 1, 2, or 4 hours post-mortem. This initial drop was amplified by delayed excision and was severe enough that -30 C storage temperature did not retard the overall decline. For nonstimulated LD muscle, the pH was maintained higher through the 30 hr sampling period at -30 C and was very dependent upon the time of muscle excision. Storage at 3 C produced an even faster decline of electrically stimulated LD muscle but somewhat hindered the pH decline of nonstimulated LD. Although differences in pH decline occurred due to electrical stimulation, excision time, and storage method, differences for initial or final sarcomere length were not observed. The electrical stimulation of prerigor beef carcasses did not affect the color of hot-boned LD or SM muscles or 48 hour cold-boned controls. Excision time, however, may affect the color

uniformity of muscles set deep into the carcass. Early excision (1 or 2 hrs) is preferable since high temperature and low pH combinations within the carcass can cause severe non-uniformity of color in muscles such as the SM.

Literature Cited

Ashmore, C. R., W. Parker, and L. Doerr. 1972. Respiration of mitochondria isolated from dark cutting beef: post-mortem changes. J. Anim. Science 34:46.

Bendall, J. R. 1972. Consumption of oxygen by the muscles of beef animals and related species, and its effect on the color of meat. I. Oxygen consumption in prerigor muscle. J. Scientific Food and Agriculture 23:61.

Bendall, J. R. and A. A. Taylor. 1972. Consumption of oxygen by the muscles of beef animals and related species. II. Consumption of oxygen by postrigor muscle. Journal of Scientific Food and Agriculture 23:707.

Bendall, J. R. and D. N. Rhodes. 1976. Electrical stimulation of beef carcasses and its practical application. European Meats Conf. London B2:3.

Cook, C. F. 1968. Rigor state, freeze condition, pH and incubation temperature and their influence on color development and extract release volume in ovine muscle homogenates. J. Food Sci. 33:200.

Davey, C. L., K. V. Gilbert, and W. A. Carse. 1975. Carcass electrical stimulation to prevent cold shortening toughness in beef. New Zealand Journal of Agricultural Research 19:13.

de Fremery, D. and M. J. Poll. 1959. Biochemistry of chicken muscle as related to rigor mortis and tenderization. Food Research 28:73.

DeVore, D. P. and M. Golberg. 1974. Oxygen uptake in postrigor bovine muscle. J. Food Sci. 39:22.

Grusby, A. H. 1976. Effects of electrical stimulation and high temperature conditioning on bovine muscle tenderness characteristics. Master's Thesis. Univ. of Fla.

Hallund, O. and J. R. Bendall. 1965. The long-term effect of electrical stimulation on the post-mortem fall of pH in the muscles of handrace pigs. J. Food Sci. 30:296.

Henrickson, R. L. 1974. Meat quality changes resulting from prerigor muscle boning of the bovine carcass. A Final Report.

Herring, H. K., R. G. Cassens, and E. J. Briskey. 1965. Sarcomere length of free and restrained bovine muscles at low temperatures as related to tenderness. J. Scientific Food and Agriculture 16:379.

Hostetler, R. L., B. A. Link, W. A. Landman, and H. A. Fitzhugh. 1972. Effect of carcass suspension on sarcomere length and shear force of some major bovine muscles. J. Food Sci. 37:132.

Kastner, C. L. R. L. Henrickson, and R. D. Morrison. 1973. Characteristics of hot-boned bovine muscle. J. Anim. Sci. 36:484.

Locker, R. H. 1958. Degree of muscular contraction as a factor in tenderness of beef. Food Research 25:304.

Locker, R. H. and C. J. Hagyard. 1963. A cold shortening effect in beef muscles. Journal of Scientific Food and Agriculture 11:787.

Locker, R. H. and G. J. Daines. 1975. Rigor mortis in beef sternomandibularis muscle at 37 C. Journal of Scientific Food and Agriculture 26:1721.

McCollum, P. D. and R. L. Henrickson. 1977. The effect of electrical stimulation on the rate of post-mortem glycolysis in some bovine muscles. J. Food Quality 1:15.

McCrae, S. E., C. G. Seccombe, B. B. Marsh, and N. G. Leet. 1971. Studies in meat tenderness. 8. The tenderness of various lamb muscles in relation to their skeletal restraint and delay before freezing. J. Food Sci. 36:556.

Meat Industry. May 1977. Hot boning.

Pirko, P. C. and J. C. Ayres. 1959. Pigment changes in packaged beef during storage. J. Food Tech. 9:461.

Ruddick, J. E. and J. F. Richards. 1975. Comparison of sarcomere length measurement of cooked chicken pectoralis muscle by laser diffraction and oil immersion microscopy. J. Food Sci. 40:500.

Savell, J. W., G. C. Smith, T. R. Dutson, Z. L. Carpenter, and D. A. Suter. 1977. Effect of electrical stimulation on palatability of beef, lamb, and goat meat. J. Food Sci. 42:702.

Savell, J. W., T. R. Dutson, G. C. Smith, and Z. L. Carpenter. 1978. Structural changes in electrically stimulated beef muscle. J. Food Sci. (accepted).

Tarrant, P. V. and C. Mothersill. 1977. Glycolysis and associated changes in beef carcasses. J. Scientific Food and Agric. 28:739.

TABLE 1. MEAN VALUES FOR INITIAL AND FINAL SARCOMERE LENGTH OF LD MUSCLES (MICRONS)

Excision time (hrs post-mortem)		Storage I Initial	Storage I Final	Storage II Initial	Storage II Final	Storage III Initial	Storage III Final
1	NS[a]	1.78	1.45	1.68	1.59	1.73	1.56
	ES[b]	1.55	1.67	1.59	1.52	1.80	1.61
2	NS[a]	1.64	1.52	1.67	1.63	1.62	1.64
	ES[b]	1.41	1.62	1.63	1.56	1.58	1.50
4	NS[a]	1.65	1.59	1.70	1.50	1.57	1.60
	ES[b]	1.65	1.63	1.62	1.58	1.67	1.57
48[c]	NS[a]					1.55	1.61
	ES[b]					1.66	1.61

[a]Nonstimulated
[b]Electrically stimulated
[c]Controls are listed as Storage III

TABLE 2. MEAN VALUES FOR INITIAL AND FINAL SARCOMERE LENGTH OF SM MUSCLES (MICRONS)

Excision time (hrs post-mortem)		Storage I Initial	Storage I Final	Storage II Initial	Storage II Final	Storage III Initial	Storage III Final
1	NS[a]	1.71	1.66	1.67	1.69	1.69	1.89
	ES[b]	1.58	1.66	1.66	1.68	1.64	1.59
2	NS[a]	1.63	1.79	1.65	1.59	1.69	1.64
	ES[b]	1.53	1.61	1.54	1.62	1.64	1.58
4	NS[a]	1.65	1.64	1.57	1.65	1.50	1.54
	ES[b]	1.60	1.68	1.63	1.64	1.54	1.60
[c]	NS[a]					1.48	1.59
	ES[b]					1.60	1.63

[a]Nonstimulated
[b]Electrically stimulated
[c]Controls are listed as Storage III

TABLE 3. MEAN VALUES FOR APPEARANCE PARAMETERS OF LD AND SM MUSCLES OVER FIVE-DAY EVALUATION PERIOD (STORAGE III, ONLY)

Parameter	Muscle	Days 1	2	3	4	5
Color Uniformity[a]	LD	5.5	5.3	5.0	4.9	4.7
	SM	4.8	4.5	4.0	3.8	3.4
Fat Cover[b]	LD	4.8	4.6	4.3	4.0	3.7
	SM	4.5	4.1	3.6	3.2	2.8
Muscle Color[c]	LD	5.5	5.3	5.1	4.9	4.7
	SM	5.3	5.1	4.8	4.6	4.2
Percent Reflectance	LD	38.3	-	-	-	47.3
	SM	41.8	-	-	-	48.0

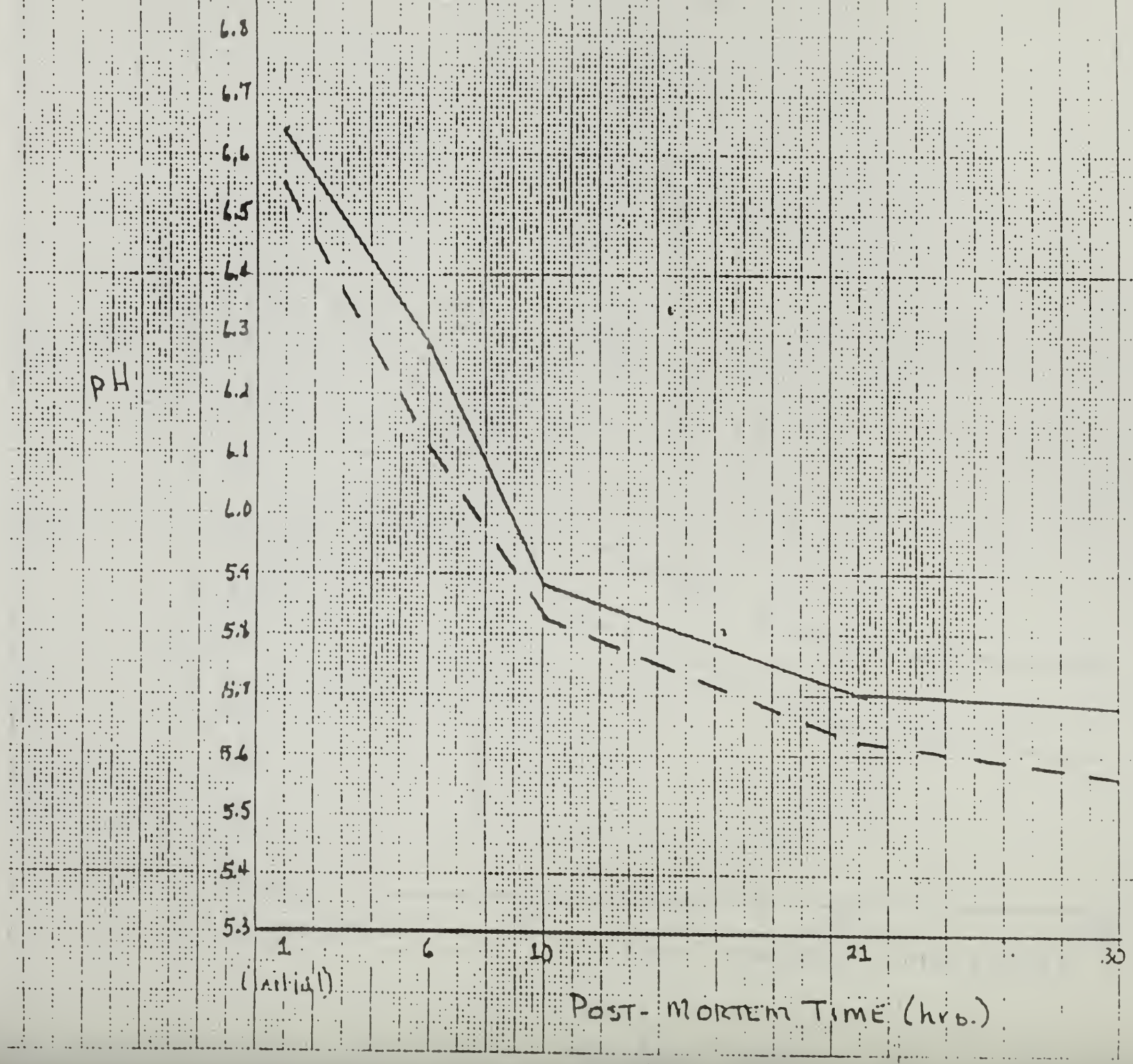
[a]6=uniform, 5=very slightly nonuniform (1-10%) and 1=extremely nonuniform (41-50%)

[b]6=very fresh, 5=fresh, 4=normal, and 1=severe or extreme discoloration

[c]9=very light cherry red, 5=slightly dark red and 1=black

Figure 1. pH decline of LD muscles stored immediately at -30 C (Storage I)

(a) 1-hr excision	————	Nonstimulated
	--------	Electrically stimulated
(b) 2-hr excision	-•-•-•-•-	Nonstimulated
	-o-o-o-o-	Electrically stimulated
(c) 4-hr excision	++++++++	Nonstimulated
	+ + + +	Electrically Stimulated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6.3
6.2
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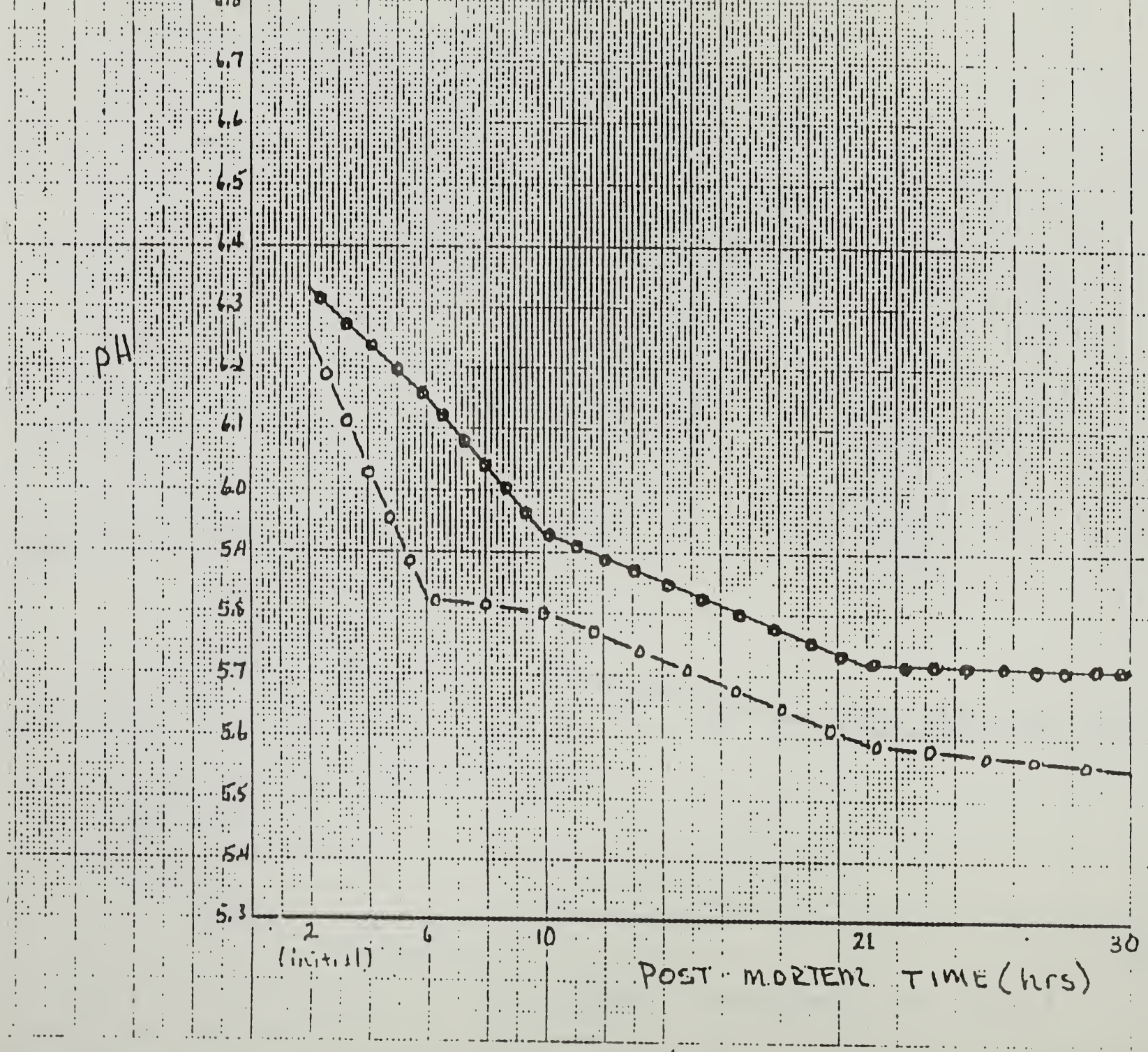
5.7
5.6
5.5
5.4
5.3
1
(initial)
6
10
21
30
Post-Mortem Time (hrs.)

Figure 1 (a)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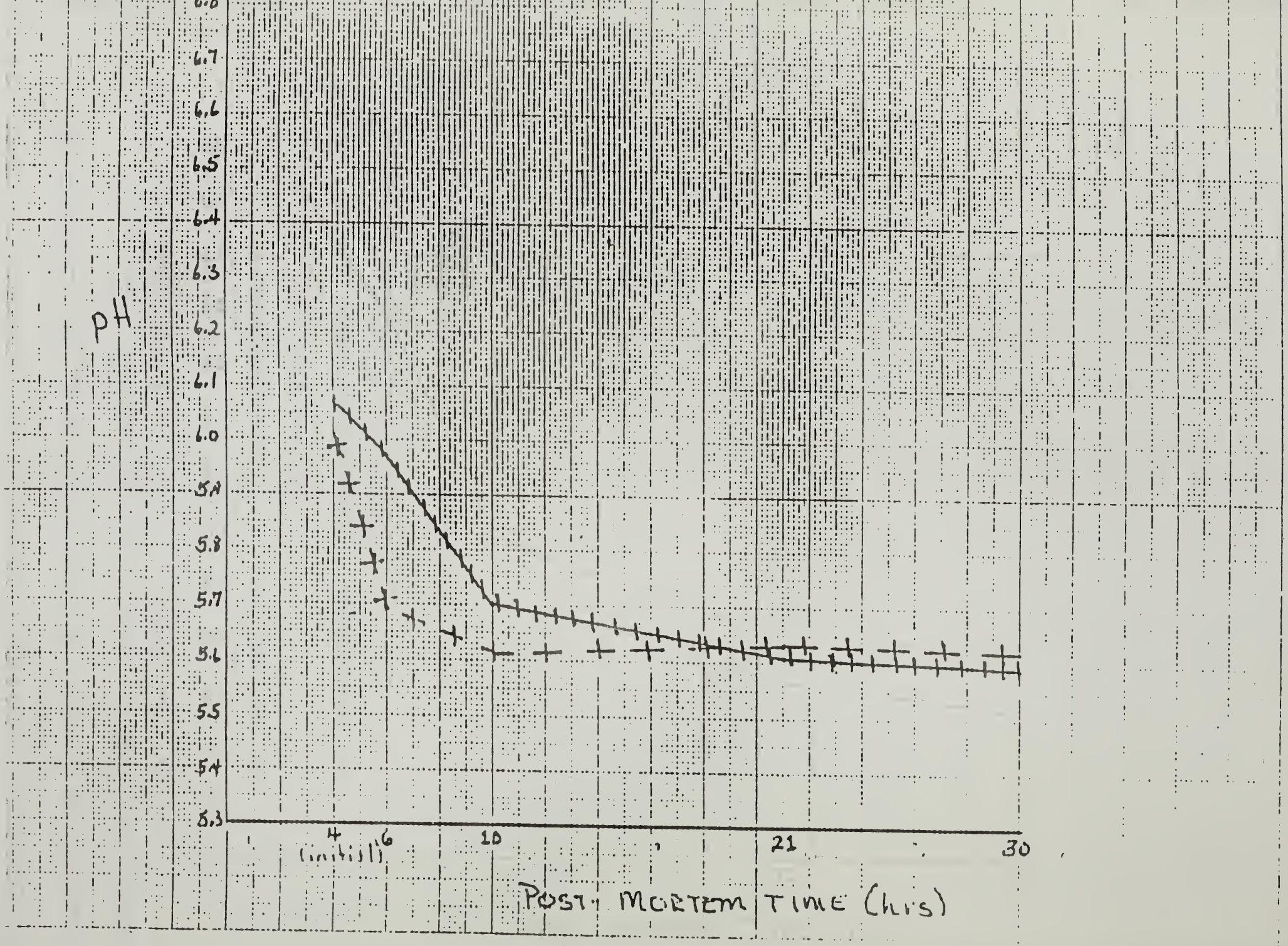
(initial)
6
10
21
30
POST MORTEM TIME (hrs)

Figure 1(b)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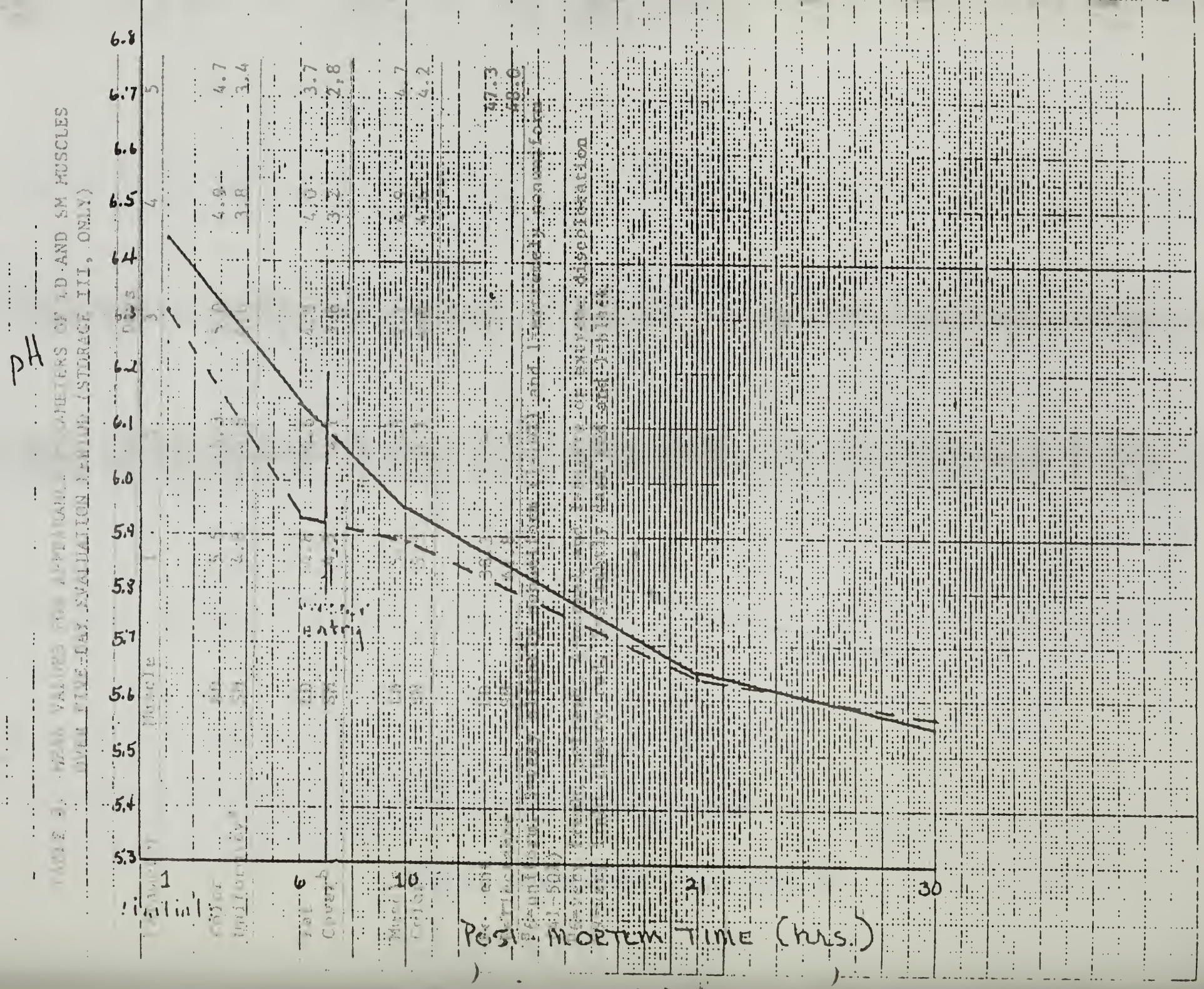
5.5
5.4
5.3
4
(initial)
6
10
21
30
POST MORTEM TIME (hrs)

Figure 1(c)

Figure 2. pH decline of LD muscles stored for six hrs at 3 C following excision and prior to storage at -30 C (Storage II)

(a) 1-hr excision	————————	Nonstimulated
	----------	Electrically stimulated
(b) 2-hr excision	-•-•-•-•-•	Nonstimulated
	-o-o-o-o-o	Electrically stimulated
(c) 4-hr excision	+++++++++	Nonstimulated
	+ + + + +	Electrically stimulated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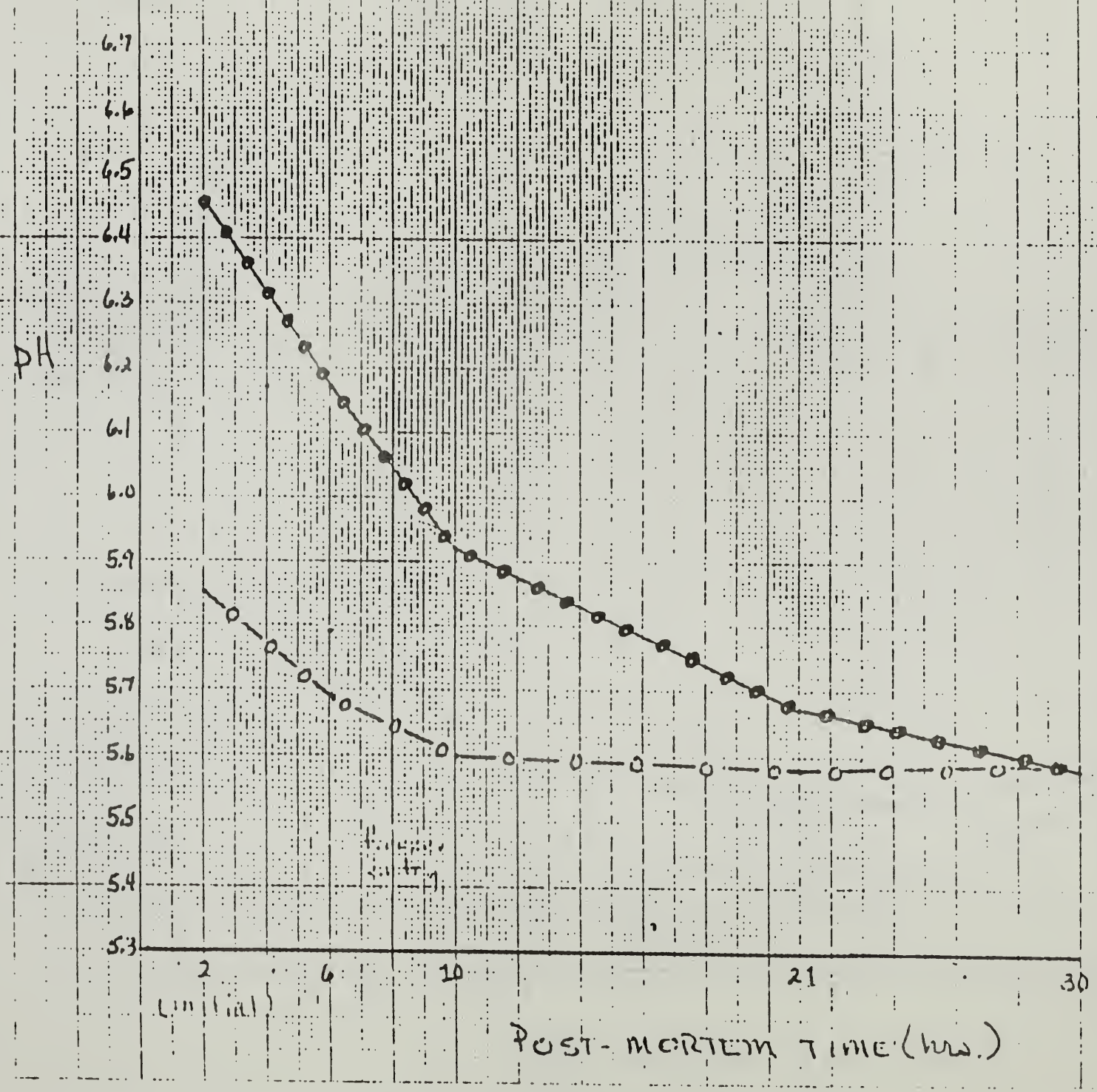
5.7
5.6
5.5
5.4
5.3
1
6
10
21
30
initial
entry
POST MORTEM TIME (hrs.)

Figure 2(a)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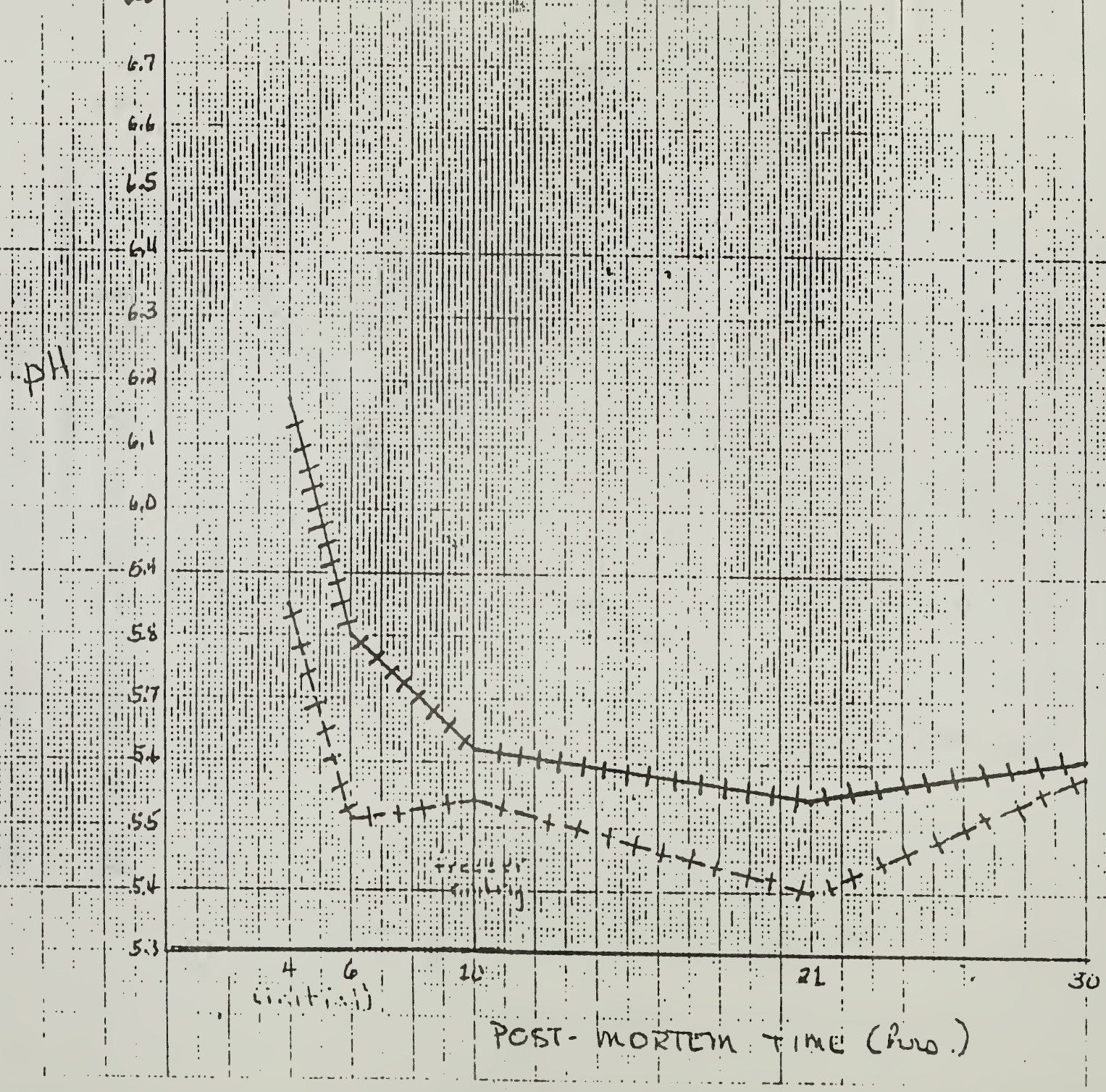
2
6
10
21
30
POST-MORTEM TIME (hrs.)

Figure 2 (b)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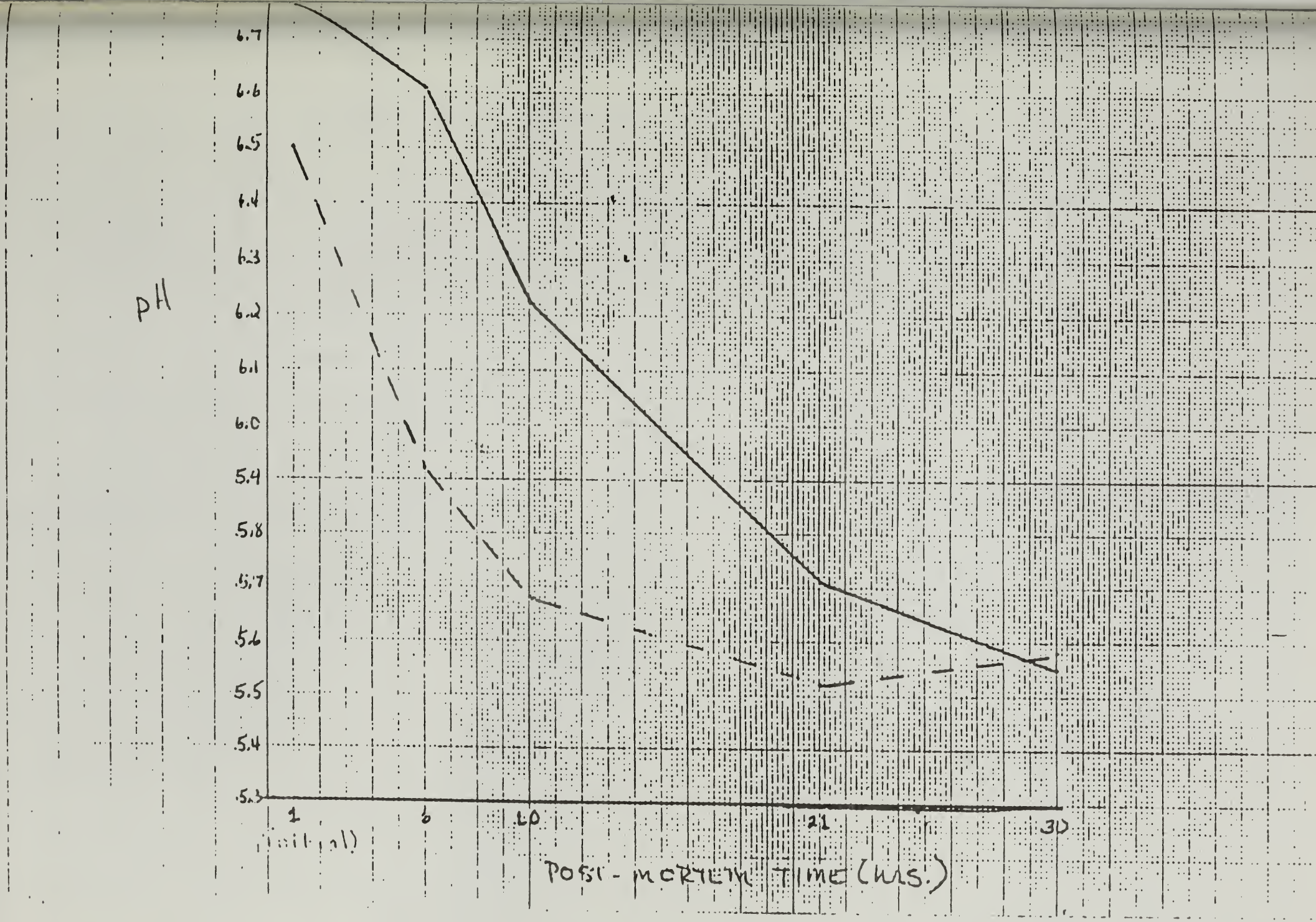
5.6
5.5
5.4
5.3
4
6
10
21
30
POST-MORTEM TIME (hrs.)

Figure 2(c)

Figure 3. pH decline of LD muscles stored at 3 C (Storage III)

(a) 1-hr excision	————————	Nonstimulated
	----------	Electrically stimulated
(b) 2-hr excision	-•-•-•-•-•	Nonstimulated
	-o-o-o-o-o	Electrically stimulated
(c) 4-hr excison	++++++++++	Nonstimulated
	+ + + + +	Electrically stimulated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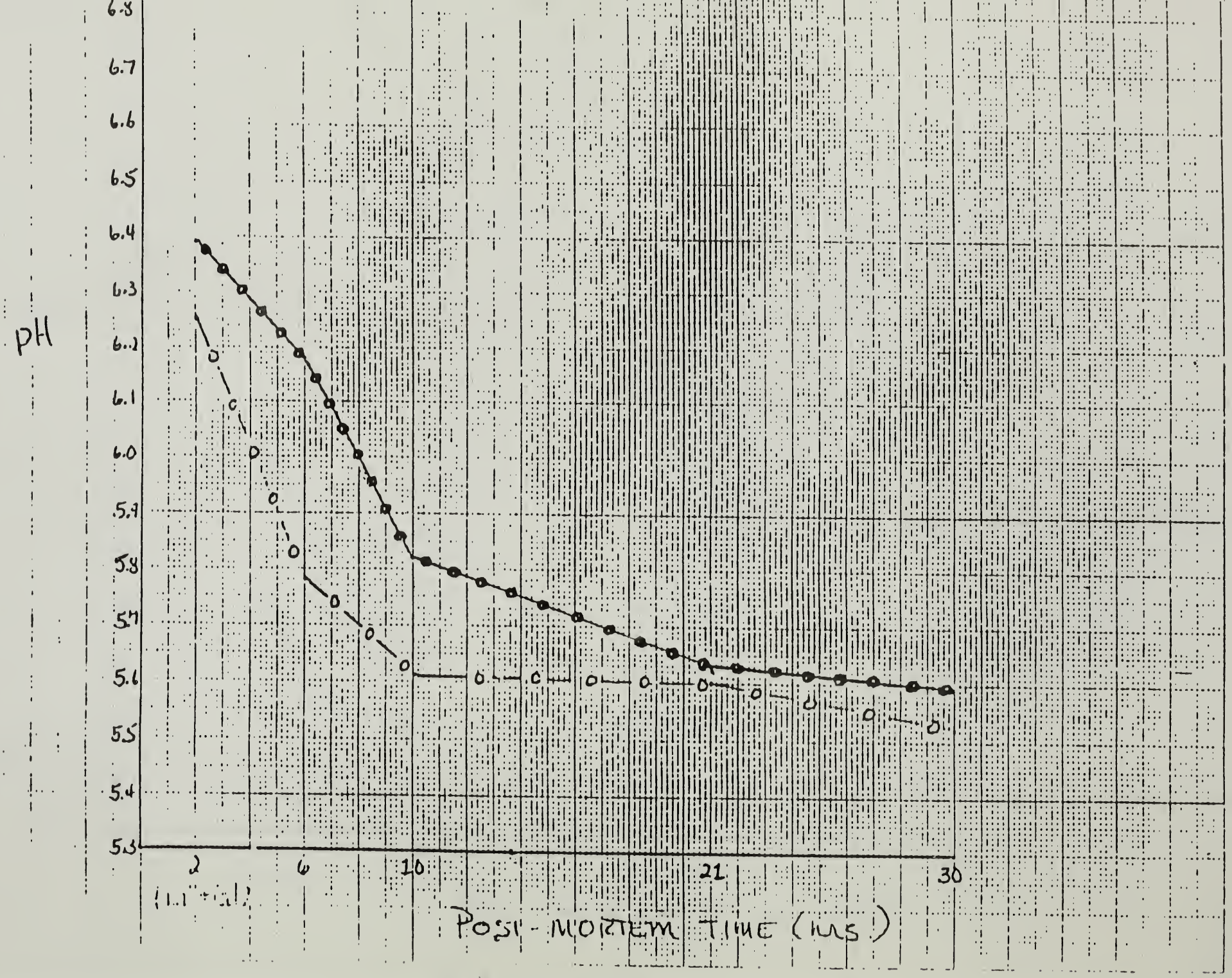
5.4
5.3
1
(initial)
6
10
21
30
POST-MORTEM TIME (hrs.)

Figure 3(a)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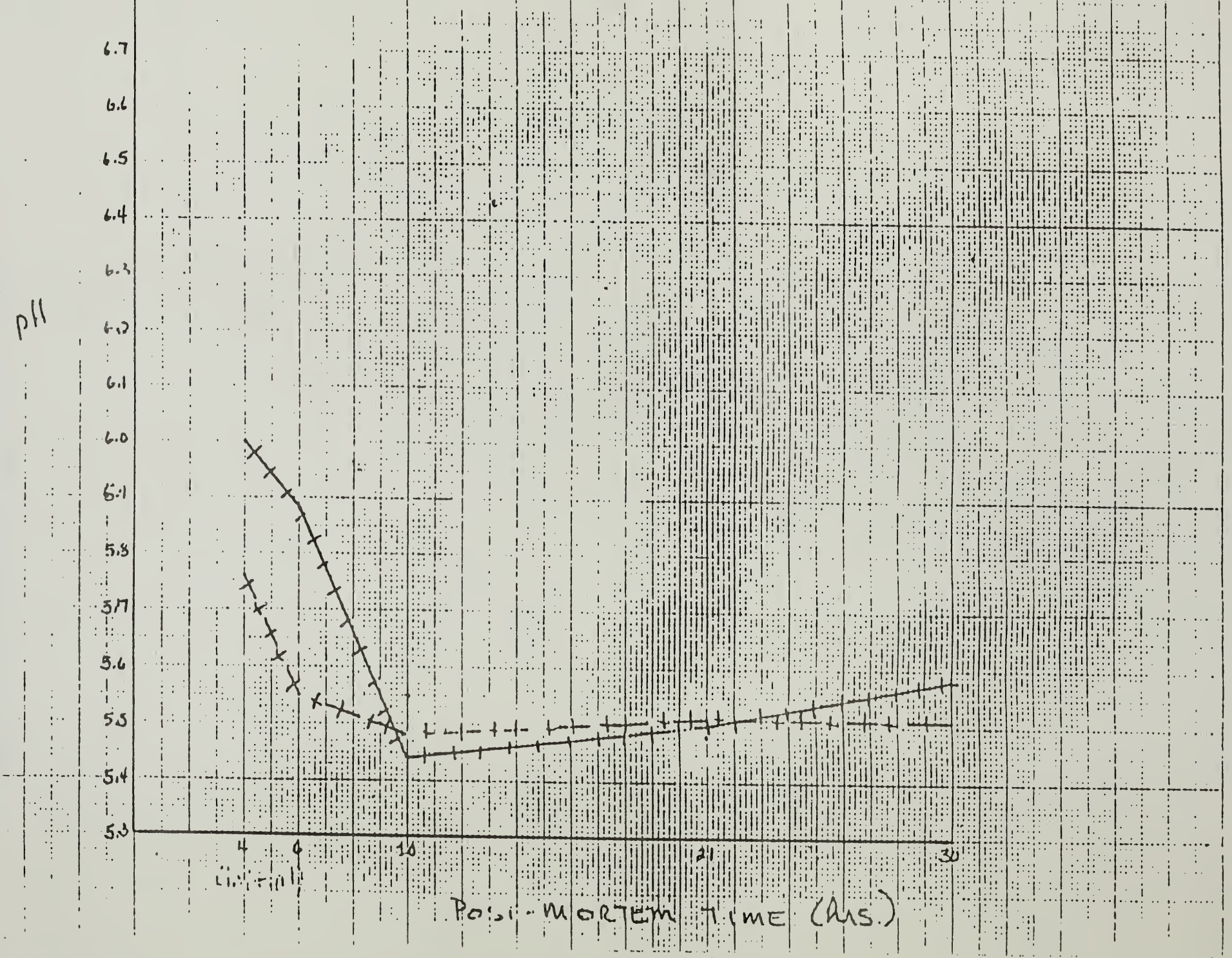
5.4
5.3
2
6
10
21
30
POST-MORTEM TIME (MS)

Figure 3(b)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5.6
5.5
5.4
5.3
4
6
10
21
30
POST-MORTEM TIME (hrs.)

Figure 3 (c)

Figure 4. Decline of SM color uniformity over five-day evaluation. Excision times differed significantly ($P<.001$).

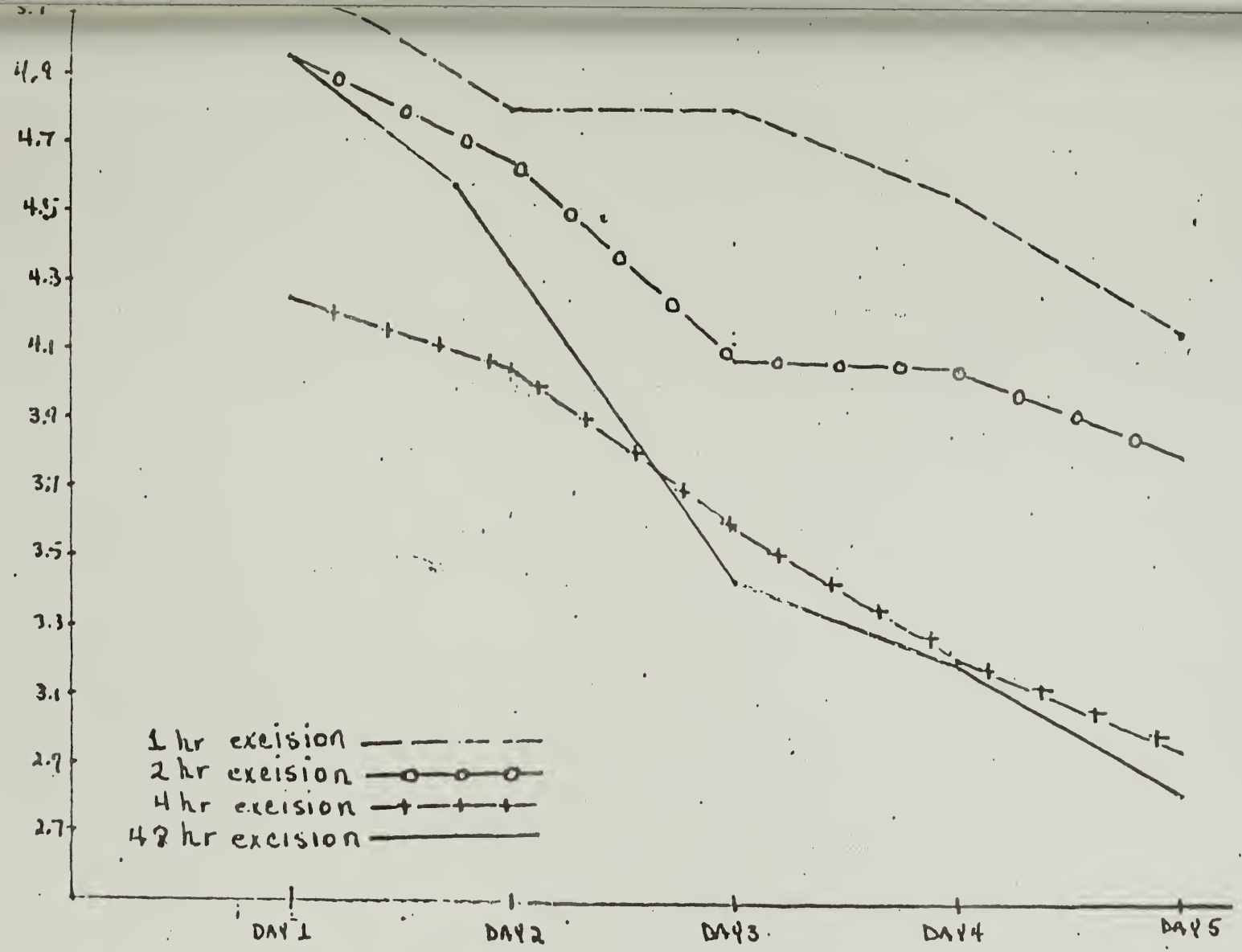

Figure 4. Decline of SM color uniformity over five day evaluation. Excision times differed significantly ($p < .001$).

Figure 5. Decline of SM color over five-day evaluation. Excision times differed significantly ($P<.05$).

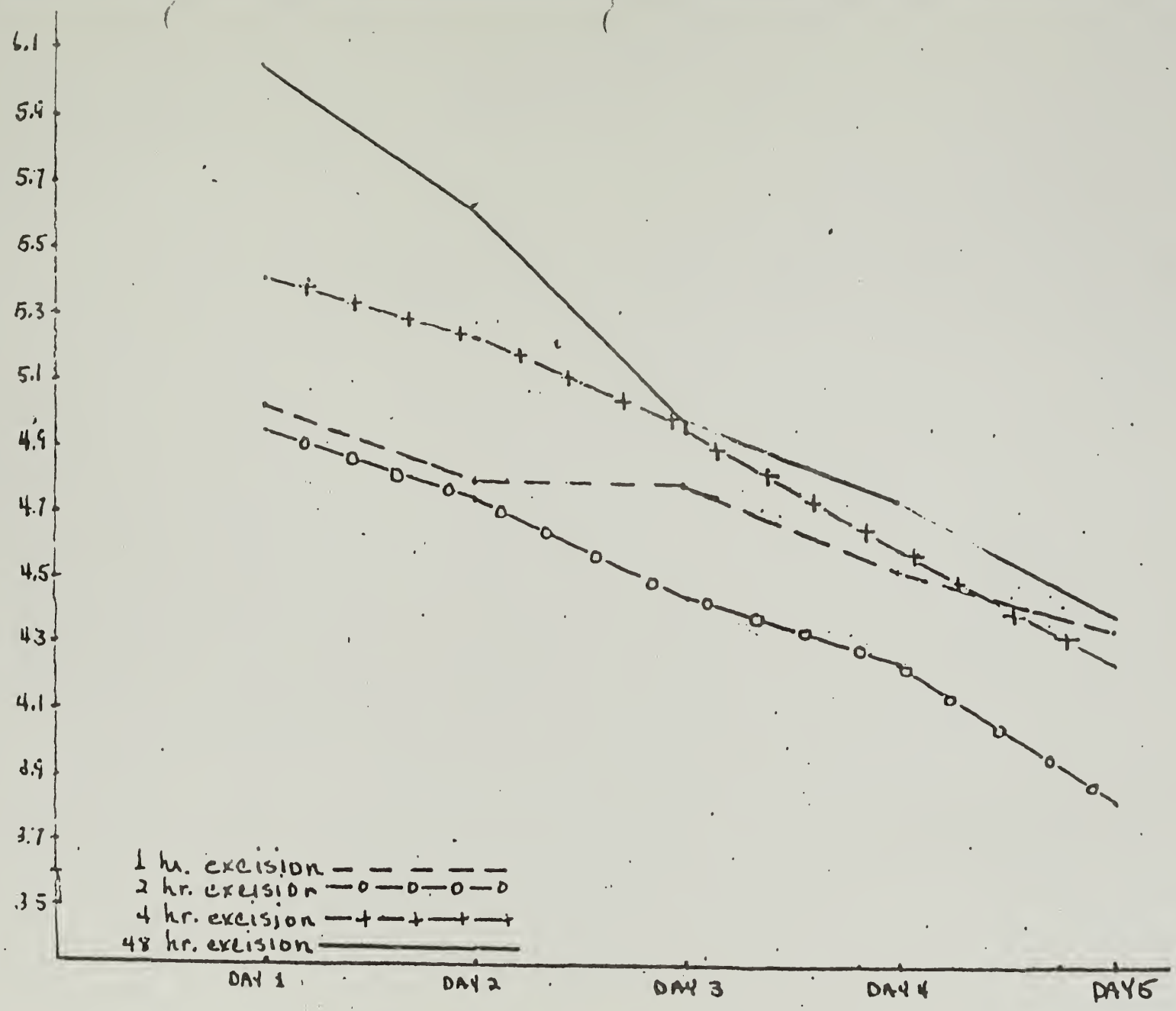

Figure 5: Decline of SM color over five-day evaluation. Excision times